Thermal Insulation Economics
For Saudi Residential Buildings

by

Hadeel Noman Saied Ahmed

A Thesis Presented to the

FACULTY OF THE COLLEGE OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

CONSTRUCTION ENGINEERING AND MANAGEMENT

July, 1991

Order Number 1354059

Thermal insulation economics for Saudi residential buildings

Ahmed, Hadeel Noman Saied, M.S.

King Fahd University of Petroleum and Minerals (Saudi Arabia), 1991

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

THERMAL INSULATION ECONOMICS FOR SAUDI RESIDENTIAL BUILDINGS

BY

HADEEL NOMAN SAIED AHMED

A Thesis Presented to the

FACULTY OF THE COLLEGE OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the

Requirements for the Degree of

MASTER OF SCIENCE

In

CONSTRUCTION ENGINEERING AND MANAGEMENT

JULY 1991

بسم الله الرحمن الرحيم

KING FAHD UNIVERSITY OF PETROLEUM AND MINERALS
DHAHRAN 31261, SAUDI ARABIA

COLLEGE OF GRADUATE STUDIES

This Thesis, written by **HADEEL NOMAN SAIED AHMED** under the direction of his Thesis Advisor and approved by his Thesis Committee, has been presented to and accepted by the Dean of the College of Graduate Studies, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN CONSTRUCTION ENGINEERING AND MANAGEMENT.**

Thesis Committee

Dr. Sadi Assaf (Chairman)

Dr. Abdul Mohsin Al-Hammad (Co-Chairman)

Dr. Osama Jannadi (Member)

20/7/91.

Dr. Abdulaziz Bubshait, Director
Construction Engineering and
Management Program

Dr. Ala Al-Rabeh, Dean
College of Graduate Studies

20-7-91

Date

I DEDICATE THIS WORK TO MY BELOVED PARENTS, MY BROTHERS AND MY SISTERS FOR THEIR CONTINUOUS SUPPORT AND ENCOURAGEMENT.

ACKNOWLEDGEMENTS

Acknowledgement is due to King Fahd University of Petroleum and Minerals for support of this research.

I wish to express my appreciation to both Dr. Sadi Assaf who served as the chairman of my thesis committee and Dr. Abdul Mohsen Al-Hammad who served as the co-chairman of my thesis committee. I also wish to thank Dr. Osama Jannadi, a member of my thesis committee, Prof. Walter Grondzik and Prof. Brooks Washburn for their comments and suggestions.

Thanks also to King Abdul Aziz City for Science and Technology who sponsored and funded this work under its project AR-8-049. And finally, thanks to Mr. Wasim Faddah, my colleague, for his assistance and thanks to all those who helped me in conducting this research.

THESIS ABSTRACT

FULL NAME OF STUDENT: Hadeel Noman Saied Ahmed
TITLE OF STUDY : Thermal Insulation Economics for Saudi Residential Buildings
MAJOR FIELD : Construction Engineering and Management
DATE OF DEGREE : August 8th, 1991

This thesis studies the thermal and economic performance of thermal insulation materials when used in villas in Saudi Arabia. The DOE-2.1C Program was used to simulate the thermal performance of a typical villa in four different Saudi cities (Dhahran, Riyadh, Jeddah and Khamis Mushait). An energy economic model was used to calculate the annual savings for both the government and the customers.

It was concluded that: (1) In Saudi Arabia, walls require either same thickness or thicker insulation materials than roofs (2) Riyadh city has the most economic benefits from using insulation materials, then Jeddah, Dhahran and Khamis Mushait, respectively (3) For walls, locating the insulation material on the interior has no economic or thermal difference from locating it on the exterior (4) For roofs, locating the insulation material on the exterior is better from the economic point of view than locating it on the interior (5) The change of discount rate has no effect on the relative performance of the insulation materials (6) When insulating buildings, customers get significant annual savings ranging from SR 1000 to SR 11000 (7) The government will get higher savings ranging from SR 2500 to SR 17000.

Finally, recommendations for different wall and roof configurations and different thermal insulation types, in conjunction with recommended U-values for each city, were given.

MASTER OF SCIENCE DEGREE
KING FAHD UNIVERSITY OF PETROLEUM & MINERALS
Dhahran, Saudi Arabia
July 1991

خلاصة الرسالة

إسم الطالب الكامل : هديل نعمان سعيد أحمد

عنوان الدراســــة : اقتصاديات العوازل الحراريه في المباني السكنيه في المملكه العربيه السعوديه

التخـــصـص : هندسه وإداره التشييد

تاريخ الشهـادة : ٨ أغسطس ١٩٩١ م الموافق ٢٨ محرم ١٤١٢هـ

تناقش هذه الرساله الأداء الحراري والإقتصادي للمواد العازله الحراريه عند استعمالها في المملكه العربيه السعوديه .

اعتمدت هذه الرساله أولا على أبحاث سابقه تم فيهاعمل مسح ميداني للفلل السعوديه وتم على ضوء هذا المسح تصميم فيلا سكنيه نموذجيه لإجراء الأبحاث عليها . كما تم عمل مسح إستبياني أخر في السوق السعوديه لمعرفه أنواع المواد العازله الحراريه المستعمله ، وأنواع الجدران والأسقف الأكثر شيوعا وإستخداما في المملكه . ولمعرفه اسعار وتكلفه العوازل الحراريه ، أجهزه التكييف وجميع الأسعار التى لها علاقه بالمشروع .

أعتمادا على المعلومات المتجمعه ، تم استخدام برنامج كمبيوتر لمحاكاه الأداء الحراري لهذه الفيلا النموذجيه في أربع مدن مختلفه في المملكه العربيه السعوديه وهي مدن الظهران ، الرياض ، جده ، وخميس مشيط . وقد تم استخدام بيانات الطقس لكل مدينه على حده في إجراء المحاكاه لكل مدينه عن طريق استخدام جدران وأسقف مختلفه في مواد البناء ونوعيه العازل الحراري المستخدم .

بناءا على البيانات المستخرجه من البرنامج ، تم إختيار صيغه

إقتصاديه لحساب مقدار التوفير السنوي لكل من الحكومه والمستهلك .

وقد تم التوصل إلي النتائج التاليه :

(١) حسب طريقه البناء الشائعه في المملكه العربيه السعوديه فإننا نحتاج إلى إستخدام عوازل حراريه في الجدران أكثر سماكه من العوازل الحراريه التي نستخدمها في الأسقف .

(٢) تعتبر مدينه الرياض اكثر المدن إستفاده من إستخدام العوازل الحراريه ، تليها مدينه جده ثم الظهران ثم خميس مشيط .

(٣) عند إستخدام العوازل الحراريه في الجدران فإن وضع هذه العوازل خارجيا أو داخليا يعطينا تقريبا نفس الإداء الحراري والإقتصادي .

(٤) عند إستخدام العوازل الحراريه في الأسقف ، فإن وضع هذه العوازل خارجيا يعتبر أفضل اقتصاديا من وضعها داخليا .

(٥) لا يؤثر معدل التخفيض في الأسعار المستخدم على نتائج الدراسه بشكل عام ، ولكنه يؤثر فقط على كمية التوفير .

(٦) عند أستخدام العوازل الحرارية ، يحصل المستهلك على توفير سنوي يتراوح من ١٠٠٠ إلى ١١٠٠٠ ريال سعودي .

(٧) عند إستخدام العوازل الحرارية ، تحصل الحكومة على توفير سنوي يتراوح من ٢٥٠٠ إلى ١٧٠٠٠ ريال سعودي .

وفي نهايه البحث تم تقديم بعض الأقتراحات التى من شأنها ان تساعد البلديات في إختيار مقاييس حراريه ثابته لمختلف مدن المملكه ، كما أنها تساعد مهندسي البناء والمصممين المعماريين على إختيار العوازل الحراريه الأنسب .

درجه الماجستير في العلوم

جامعه الملك فهد للبترول والمعادن

الظهران ، المملكه العربيه السعوديه

التاريخ : ٢٨ / ١ /١٤١٢ هـ

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1
INTRODUCTION

1.1 General

Since the early existence of human beings, man has been conscious of his energy resources. This consciousness was related to man's needs for staying alive and safe from wild animals. Thus, he had to gather the maximum possible amount of wood and dry grass in order to keep his fire ignited as long as possible.

throughout the development of mankind, new energy resources have been discovered as his energy consumption increased because of the new difficulty and complexity of life which came step by step with the new discoveries and inventions. Because of the fact that fossil fuel formation takes thousands of years, a real shortage of such fuel has emerged and this has forced mankind to become more conscious of these valuable resources.

Nowadays, fossil fuel shortages and rapidly rising costs of energy are becoming a critical problem all over the world. The industrial nations, because of their huge dependency on energy resources, were the first nations to pay attention to this problem. Thus, new regulations for consuming energy have been introduced in order to decrease energy consumption and make the available energy resources continue to serve us for at least the coming century, until some new dependable energy resources are discovered.

Studies have showed that buildings consume about 40% of the annual energy consumption in the United States itself [1]. In Saudi Arabia and GCC countries, studies have showed that these countries could save up to 33% of the annual energy consumption by using insulation [2]. This figure can show us the huge responsibility of designers and engineers in energy conservation. This energy conservation could be achieved by using new construction techniques and implementing good thermal insulation in the buildings they design and construct.

1.2 Statement of the Problem

The construction industry is one of the huge industries by which most countries' economies are affected. This industry consumes and requires huge amounts of materials, equipment, labor, time and money. Day by day, new techniques and improved methods are introduced to this industry in order to develop it and make it as profitable as possible.

In Saudi Arabia, as in all other countries, the construction industry is considered to be one of the largest industries upon which the local economy depends. The problem in Saudi Arabia is that this industry is still using the traditional building techniques, while all over the world there are so many new building techniques which can be applied in Saudi Arabia and have great advantages. One of the new improved techniques is the use of thermal insulation materials in buildings. The need for this type of construction techniques has emerged because of the increased demand on the energy resources, which in term led to the increase in the energy costs.

In Saudi Arabia, people were, until the recent past, unconscious of the energy costs increase. This was due to the following reasons [3]:

1. The historically low cost of energy, supported in part by generous Government subsidies,
2. The long payback period associated with the traditional cost of insulation materials, which is directly related to the low cost of energy, and
3. A general incompatibility of some insulation materials with common construction details, especially for residential construction.

Thus, Saudi constructors resist using thermal insulation in buildings because of the cost of the insulation itself, the cost of installation, and the cost of changes in the construction techniques which have to go with the use of insulation materials. Most owners, in this respect, do not know that the positive impact of the use of insulation is the savings in energy costs at a later date. This is quite fair since we do not expect that all owners know about the life-cycle costs.

Because of the societal benefits we can gain by establishing minimum insulation requirements forced by building codes, the Gulf Cooperation Council has established some insulation standards. But because of the previously mentioned conditions in Saudi Arabia, we doubt that these standards will be used by Saudi constructors unless they are forced to do so. In addition to this, each country in the G.C.C., especially Saudi Arabia which covers a huge area that extends very far away from the Arabian Gulf region, has to establish its own thermal insulation standards which have to be applicable to the different regions of the country.

Although thermal insulation is not widely used in Saudi Arabia, thermal insulating materials are available either through import or from some domestic firms which are engaged in the manufacture of resistive insulation materials. These include polyurethane, polystyrene, and glass wool/fiber products [3]. Thus, with this variety of materials produced in Saudi Arabia, different approaches to meeting thermal insulation standards for buildings might be taken, but the real problem we encounter is that we have to start thinking seriously of making our own applicable standards which the Saudi constructors must be forced to follow through building codes.

1.3 Literature Review

1.3.1 General

Providing a shelter against the extremes of the outdoor environment is one of the primary objectives in the construction of a building. Thus, the designer of a building is responsible for the microclimate created within the space enclosed by the structural shell. The thermal performance of a proposed building can be assessed by various means such as full scale field experiments, laboratory tests or simulation models. However, computer simulation is the most widely used method because of the high cost of the other methods and their restrictive nature.

The physical behavior of a building structure can be simulated by means of an abstract model. Consequently, any simulation model is an approximation of reality. Therefore, the relative merit of each model should be judged according to its specific objectives and the relevant field validations.

The building designer, at the design stage, needs an inexpensive and fast method of predicting the thermal performance of the proposed structure. But usually at this stage, the available input data are limited and the configuration is not fully defined [4].

In the recent years, there have been considerable advances in the application of computers to building design. Powerful drafting systems have emerged which have stimulated a demand for complementary performance appraisal software [5].

In this thesis, mathematical simulation of a number of different building configurations located in different climatic areas of the Kingdom are used as more reasonable and appropriate than physical modeling. This is due to the fact that physical modeling is more expensive and requires longer periods of time. Here, a review of some issues related to building energy simulation will be given.

The purpose of mathematical modeling, as indicated by Simon, "is to gain understanding and the ability to predict behavior of the system being studied [6]." Since this same purpose applies to other forms of modeling, and because of the availability of several possible forms of modeling to describe any given system, user preference is the main factor upon which the choice of a model type to be used depends. As Simon suggests, those models which are most easily constructed and yield the greatest amount of useful information are the most valuable models for engineers [6]. In the case of building design, the simulation of building energy use is one of the areas where mathematical modeling is the most suitable form of modeling to be selected.

Simulation is a valuable tool in meeting the client's demands of higher standards of environmental quality and energy efficiency. Thus, simulation techniques have a lot to offer both architects and building services engineers. The building energy performance evaluation by simulation tools is now available to a wide variety of users. The technical problems and deficiencies of first generation simulation tools have been overcome and simulation is now in regular use in several leading design practices [7].

System simulation indicates the observation of a synthetic system which imitates the performance of a real system [8]. Such a type of simulation can be accomplished by calculation procedures. Thus, system simulation assumes proper knowledge of the performance characteristics of all components. This does not mean that mathematical models are easy to construct. In fact, a model for complex systems may involve hundreds of distinct variables and high-level mathematical relationships.

As indicated by Stoecker,"simulation is used when it is not possible or not economical to observe the real system [8]." It is also used when the system to be observed is still in the design stage and it doesn't exist yet.

A general picture of the elements of building energy simulation is shown in Figure 1. Here, the context is climate. The modeling target is the building's systems (its form and fabric, its plants and systems, its leakage and pressure distribution, its control systems, and the occupant's actions). The underlying issue is low cost, but advanced computing resources. The objective function is the provision of comfort for an acceptable fuel consumption [5].

The system types which may be simulated mathematically are classified as being: continuous or discrete, deterministic or stochastic, and steady state or transient [8].

In a continuous system, the energy or mass flow through the system is continuous, while in the discrete system the energy flow is treated as a certain number of integers (totally separate occurrences). In a determin-

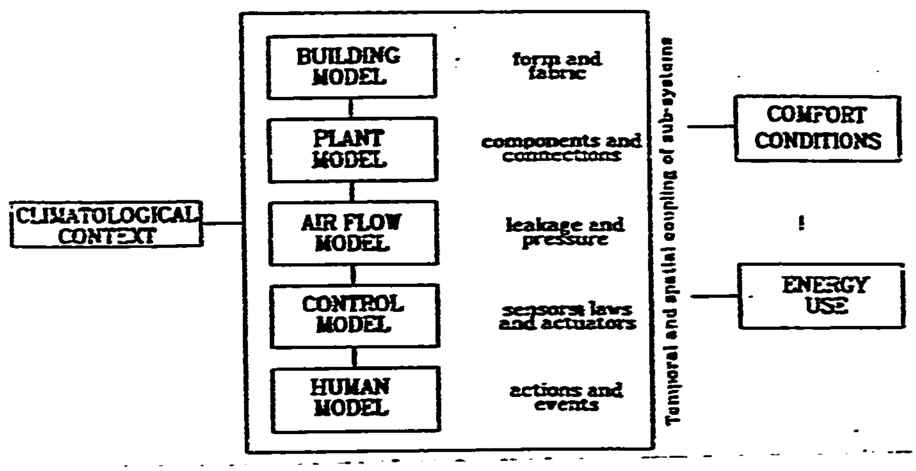


Figure 1.1: The elements of advanced building energy simulation [5].

istic system, the input variables are precisely specified, while in the stochastic system the input variables are uncertain and are either random or probabilistic. In a steady state system, the output results from a set of variables which are fixed over time, while a transient system involves output resulting from a system which is changing over time. In general, discrete-deterministic-steady state systems are easiest for simulation [9].

In fact, mathematical simulation is widely used in all areas of building design due to the relative ease of formulation, ease of use, and ability to substitute for the construction of a real system. The approach of using mathematical simulation of building components for building design is cheaper, faster, and easier than using a trial-and-error construction of prototypes approach.

The state of mathematical simulation in building design is summarized by Stoecker quite nicely: "Performance characteristics of components can be expressed in one of three forms- graphical, tabular, or equation. The prediction of system performance by finding the interaction of performance curves of the components is a standard engineering procedure, but it is feasible only for small systems with two or three components. Searching through a multiplicity of tables to find the operating conditions that satisfy all of the components is also not practical. The one method left is to express the performance of the components in equation form and solve these equations simultaneously. With the availability of a digital computer, it is possible to solve dozens or even hundreds of simultaneous equations, each representing the performance of a component in the system [8]."

1.3.2 Historical development of L.C.C.

Life cycle costing (LCC) is an economic assessment of an item, area, system, or facility, considering all the significant costs of ownership over its economic life, expressed in terms of equivalent Saudi riyals [10]. In general, LCC was first published by Eugene L. Grant in his book "Principles of Engineering Economy" which was published in 1930 and became the classic reference for all who dealt with the effects of engineering economics.

In 1933, the comptroller general of the United States published one of the first government references to LCC. During the decade 1940-1950, Larry D. Miles originated the idea of Value Engineering (VE) at the General Electric Company. VE was much broader than life cycle analysis because it was incorporating functional studies along with a total cost concept. Alphonse J. Dell'Isola was the earliest proponent of VE for the construction industry after publishing an application guide in 1972. In the United States, the years 1950-1960 were relatively static with regard to LCC development. However, during that period in England, P.A. Stone began his work at the Building Research Station, which resulted in the publication of two major texts concerning cost-in-use in the decade to follow.

In 1961, the Building Research Institution in Washington, D.C. sponsored a conference entitled "Methods of Building Cost Analysis" in which the papers presented procedures for developing life cycle cost analysis for buildings, their enclosure, lighting and heating, ventilating, and air-conditioning systems. During the years following 1961, the development of LCC continued and was particularly concentrated on the projects of the Department of Defense and hospital facilities in the United States. In 1977, Florida state became the first to formally adopt LCC and require consideration of initial, energy, operation , and maintenance costs as criteria for the design of buildings over 5000 square feet. All other states included LCC as part of energy legislation, with the exception of Alaska, which issued a law requiring LCC procurement of all public facilities in 1975. Since 1977, two request-for-proposal documents for the preparation of value analysis of conceptual design alternatives has been issued by the Department of Revenue for the state of Illinois Capital Development Board.

In April 1977, a formal set of guidelines for architects and engineering consultants was issued by the American Institute of Architects (AIA). This guide presents a method for computing the present value and uniform annual values for total building costs and recommends techniques for incorporating the results into the building decision process. AIA has also sponsored LCC seminars in conjunction with the American Consulting Engineers Council. In November 1978, the National Energy Conservation Policy Act was established by the public law 95-619. As determined by methods described by the legislation, this law mandates that all new federal buildings be life cycle cost effective. When designing new federal buildings, cost evaluation must be made on the basis of life cycle cost rather than initial cost. But for existing buildings, retrofit measures should be taken to improve their energy efficiency in general and to minimize their life cycle cost.

In May and June of 1979, public hearings were held regarding a proposal by the Department of Energy that LCC analysis be required in all new construction or retrofitting projects in federal buildings. This proposal would require LCC methods to be used in early design and planning to determine which energy-saving investment to use, while for existing buildings, the proposed change would require retrofit investments to be ranked by cost savings. In 1979, Building Energy Performance Standards (BEPS) became available for implementation and was based on groundwork by ASHRAE's (American Society of Heating, Refrigeration and Air Conditioning) standard 90-75.

On January 23, 1980, the Department of Energy issued a final rule to establish a methodology and procedures to conduct life cycle cost analysis. The methodology involves estimating and comparing the effects of replacing the systems of a building with energy-saving alternatives in existing federal buildings and of selecting among alternative building designs containing different energy-using systems for a new federal building [10].

"Current developments are pushing the frontiers of engineering economics to encompass new methods of risk, sensitivity, and intangible analysis. Traditional methods are being refined to reflect today's concerns for resource conservation and effective utilization of public funds [11]."

1.3.3 Previous studies in the Gulf region

In the Gulf region, two studies, with similar objectives to our study, were conducted. These two studies are:

1. Study 1:(Energy Conservation Program) conducted by the Ministry of Electricity and Water in the State of Kuwait [12].
2. Study 2:(Energy Efficiency Standards for Buildings in the Kingdom of Saudi Arabia) conducted by the ENSAR Group, Inc. and sponsored by the Arabian Fiberglass Insulation Company, Ltd. in the Kingdom of Saudi Arabia [24].

We will refer to these studies as the Kuwaiti study and the ENSAR study respectively.

The goal of such studies is to issue guidelines for energy conservation. Our study is considered to be the most recent study in its type in the Gulf region.

1.3.3.1 Kuwaiti study

This study was conducted in 1983 with the major goal of introducing a guideline for energy conservation in Kuwaiti buildings. It included residential and commercial buildings. The residential part, our consideration, was performed as follows [12]:

1. Typical base-case buildings: In this stage, six buildings were selected as representatives of the Kuwait residential sector. These types are
   1. Single story villa.
   2. Single story villa with courtyard.
   3. Two story villa.
   4. Limited income house.
   5. Medium income house.
   6. Apartment building.
2. Base-case parameters and operating conditions: In this step, the overall description of each building is entered into the simulation program (Kuwait Energy-Use Simulation of Buildings {KESB}) which is an adaptation of the DOE-2.1 program.
3. Base-case energy-use analysis: In this step, each building with its description and operating conditions is simulated for:
   1. Hourly cooling load.
   2. Hourly cooling electric power consumption.
   3. Hourly total electric power consumption.

4. Annual total electric energy consumption.

4. Single-effect conservation measures: In this step, 11 single effect cases were performed to study the effect of various conservation measures.

5. Optimization modelling: In this step two things were required to determine the best set of energy conservation measures. These are:

   1. Simple models in the form of algebraic formulae that can predict peak cooling load, annual electric energy and annual electric cooling peak as functions of building parameters.

   2. A performance index representing the objectives of the optimization process.

6. Selection of optimum parameters: In this step, an optimization program had been developed to select insulation levels for walls, roofs, floors, as well as glass type and A/C systems so that the profit is maximized.

1.3.3.2 ENSAR study

This study was conducted in 1989. It was performed as follows [13]:

1. Typical base-case buildings: In this step, two residential building types were selected to represent the residential buildings. These are:

   1. Two story villa.

2. Large villa.

2. Setting base-case parameter and operating conditions: In this step the overall description of each building was determined by an analysis of the current existing Saudi Arabian residential building market.

3. Base-case energy analysis: In this step, each base-case building with its description and operating conditions is simulated for:

   1. Hourly cooling load.
   2. Hourly cooling electric power consumption.
   3. Hourly total electric power consumption.
   4. Annual total electric energy consumption.

4. Determining single-effect conservation measures: In this step, 16 measures were applied to each building.

5. Overall thermal transfer value analysis: In this step, the concept of an overall thermal transfer value (OTTV) was used to develop an appropriate criteria for the building envelope for the Kingdom of Saudi Arabia. The OTTV formulation is performance-based which allows a building designer freedom to vary important wall characteristics to meet specific design objectives and still comply with the OTTV requirements for the wall. This

approach involved evaluating the correlation between selected envelope parameters known to be important to energy use and the resulting changes in the energy consumption of the base-case building.

1.4 Objectives

The main objectives of this thesis are:

1. To select an economical evaluation model to be used with building simulation studies for analysis of insulation alternatives.
2. To quantify the economic parameters related to the use of insulation in the Saudi Arabian environment.
3. To perform energy simulations for a typical villa considering different insulation applications.
4. To compare the economic performance of these different building construction assemblies for the typical villa.
5. To define the most economical insulation options for villas in Saudi Arabian environment from the above findings (conclusions and recommendations).

1.5 Research Methodology

In order to achieve the objectives of this thesis, the following steps will be followed:

Step 1: Search for the available economic evaluation models.

Step 2: Among the founded models, select the one which most properly suits the Saudi environment.

Step 3: Quantify the economic parameters related to the use of thermal insulations in the Saudi environment.

Step 4: Design a typical Saudi villa.

Step 5: Search for the available thermal insulation materials in the Saudi market and collect their prices, properties and all other related costs.

Step 6: Collect all costs related to building energy economics: air conditioning systems cost, maintenance cost, energy consumption cost and depreciation cost.

Step 7: Set all possible walls and roofs configurations which are mostly used by the Saudi constructors.

Step 8: Run the DOE-2 program to simulate the typical Saudi villa performance with different walls and roofs configurations for the four cities, Dhahran, Riyadh, Jeddah and Khamis Mushait.

Step 9: Using the QUATTRO PRO program (available in the market) and the INTERACTIVE CHART UTILITY program (installed in the mainframe at King Fahd University of Petroleum and Minerals), present the results we got.

Step 10: Compare among the different insulation materials and walls and roofs configurations to find the most economical insulation materials and walls and roofs configurations.

Step 11: Conduct a sensitivity analysis by selecting different discount rates to examine the validity of the economic parameters we sat.

Step 12: Based on the findings, recommend standard U-values for Saudi residential buildings.

1.6 Scope of the Study

This study will be limited to the Saudi residential villas. The thermal insulation materials are those which exist in the Saudi markets till 1990. The walls and roofs configurations are those which are mostly used by the Saudi constructors.

1.7 Significance of the Study

Nowadays, Saudis are becoming more conscious about energy conservation. They become aware of every riyal they spend and try to achieve their vital needs by the least expense. Most Saudis understand the idea and the benefits of thermal insulation and try to use it.

This study will be as a helpful guide for both government and customers. For the government, municipalities could issue codes which force constructors to use thermal insulation materials and thus save the government millions of riyals through the decreased amounts of energy consumed. This study will help the customers to select the most suitable thermal insulation materials with any construction configuration they would use. Through the use of the findings of this study, a lot of money could be saved for both government and customers.

1.8 Thesis Organization

This thesis is divided into eight chapters. Chapter One gives a general introduction to the study, a statement of the problem, a literature review, objectives of the study, research methodology and the significance of the study. Chapter Two talks about the thermal insulation materials in Saudi Arabia, their availability and prices. It also talks about some available thermal insulation standards in some big Saudi companies and other Gulf countries.

Chapter Three gives an idea about the research project. It shows a summary of the project, characteristics of the typical Saudi villa, building loads and systems descriptions and the walls and roofs configurations used. In Chapter Four, the models of insulation economics are described, evaluated and quantified.

The fifth chapter explains the simulation process. It gives an introduction to the DOE-2 program, and explains the simulation inputs and outputs. Chapter Six summarizes all the results. For each city, it presents thermal and economic performance of walls and roofs. combined performance, optimization graphs and U-values for both government and customers at a discount rate of 10%. It also compares the results among the four cities. In Chapter Seven, a sensitivity analysis is conducted to test the validity of the choice of the 10% discount rate by applying different discount rates (5% and 15%). Finally, Chapter Eight gives a summary of the results, conclusions and recommendations for further research.

Chapter 2
THERMAL INSULATION USE IN SAUDI ARABIA

2.1 Availability of Insulation Materials in S.A.

After the industrial revolution throughout the world, new building materials have been found in accordance with new construction methods and technology. Insulation materials were one of these new improvements in building materials.

In Saudi Arabia, after the discovery of oil and its appearance as a very important source of energy, the national market has become connected to the international markets; thus, many new materials and construction techniques were imported to the Kingdom. The use of these new building materials and construction techniques was an indicator of modernization. However, people started to use these new materials heavily without paying attention to their characteristics and their compatibility to the environment of Saudi Arabia.

Since the drop in oil prices, people in Saudi Arabia have become more cost-conscious and they have started to notice the disadvantages and shortages of the new construction systems which were not found in the traditional buildings. One of the main problems was the bad thermal behavior with respect to the severe weather conditions in Saudi Arabia. Thereafter, Saudis have become aware of using insulation materials to improve the thermal behavior of their buildings and to conserve energy.

Generally, thermal insulation materials could be classified into two basic categories [3]:

1. Resistive insulation, and
2. Capacitive insulation.

They are different both in performance and basic properties. Resistive insulation is effective in retarding heat flow because it is a poor conductor of heat, while capacitive insulation is effective in retarding heat flow because heat is stored in the insulation rather than being transmitted through it [3].

"In Saudi Arabia, capacitive insulation is currently more important than resistive insulation since most construction is of fairly massive materials with little or no specific use of resistive insulation [3]."

The most important thermal insulation materials which are available in the Saudi markets are [14]:

1. Polyurethane / polyisocyanurate foam.
   a. Spray foam with diathon layer.

b. Boards and panels.

c. Sheet.

d. Injection between cavity.

2. Polystyrene extruded and expanded.

a. Board.

3. Fiberglass.

a. Loose fill.

b. Batt.

c. Bonded.

d. Board.

4. Perlite.

a. Loose fill (on steel).

b. Perlite concrete.

c. Roof board (on concrete slab).

5. Mineral fiber.

a. Batt.

b. Loose fill.

c. Bonded.

6. Elastomeric foam (Diathon).

7. Phenolic foam.

8. Vermiculite.

a. Zonolite.

9. Glass wool.

10. Gypsum board attached to insulation board.

11. Light weight prefabricated insulative concrete block filled by insulation.
12. Foamglass.
13. Insulation as exterior finish dravit.

2.2 Prices of Insulation Materials in S.A.

Based on a recent field survey [15], the prices for some thermal insulation materials available in the Saudi market are presented in the tables shown in Appendix A. The installation costs are presented in Appendix B. These costs are for the year 1990, and they are presented as were collected from the manufacturers, distributors and contractors.

2.3 Saudi and G.C.C. Standards for Insulations

Energy standards and codes differ from one place to another and from one country to another. In common, all these standards provide requirements regarding energy conservation.

In the Gulf region, some countries started to issue their own energy standards. The Gulf Countries Council (G.C.C.) have issued an energy standard which is recommended to be used by the Gulf countries. These standards might work properly in all Gulf countries except Saudi Arabia whose area is very wide and extends very far away from the Gulf region. Thus Saudi Arabia will need its own energy standards which should differ from one region to another throughout the Kingdom.

Kuwait is one of the earliest countries in the Gulf region which considered setting its own energy standards. In the early seventies, the Ministry of Electricity and Water in the State of Kuwait started planning an energy conservation program which led to the appearance of the "Kuwait Code of Practice" (MEW/R-6). The main purpose of this code was to decrease thermal loads and energy consumption in buildings [12]. Different recommended U-values for walls and roofs are given for different types of buildings.

For the Gulf countries, thermal insulation regulations were prepared and agreed upon the ministers of electricity in the G.C.C. member states in their meeting in Doha, Qatar 30/31 October, 1984 [16]. The proposed U-values are 0.74 W/m**2-C for walls and 0.75 W/m**2-C for roofs.

In Saudi Arabia, the Government has not yet issued its own energy standards, yet some big companies in the Kingdom have their own energy standards. Among these companies is ARAMCO. Yet, ARAMCO's standards are performance standards, thus no specific U-values are given. Instead, it requires R-12 in walls and R-21 in concrete roofs. However, there is no written document that aids designers in reaching appropriate levels of energy conservation strategies for various projects [13].

Chapter 3
THE RESEARCH PROJECT

3.1 Project Summary

The data and experimentations in this study were done in conjunction with the KACST (King Abdul-Aziz City for Science and Technology) research project AR-8-049. This project is entitled "Thermal and Economic Performance of Insulation for Saudi Buildings". The project is sponsored by KACST and is performed by some KFUPM faculty members. The purpose of this project is to examine the thermal and economic performance of the thermal insulations when used in Saudi buildings.

In this project, a test building at KFUPM was built in which different configurations of walls and roofs and different thermal insulation materials were used. The thermal performance of this test building was collected hour by hour for twelve months. The second step was to simulate the thermal performance of the walls and the roofs with different cities weather files by using the DOE-2.1C energy simulation program. The simulation process was run by simulating a typical Saudi villa under different Saudi cities weather conditions. The energy simulation outputs provided the researchers with the thermal performance of the typical villa in four Saudi cities (Dhahran, Riyadh, Jeddah and Khamis Mushait).

Based on the thermal performance, the economic performance could be achieved by applying suitable economic models. The final results will lead to the process of determining the most economical thermal insulation materials in Saudi Arabia, which in turn will lead to the process of establishing a Saudi building code for thermal insulation.

3.2 Typical Saudi Villa Characteristics

For the purpose of the energy simulation studies, the parameters of the typical Saudi villa have been defined. This included the architectural design, building materials and mechanical A/C systems.

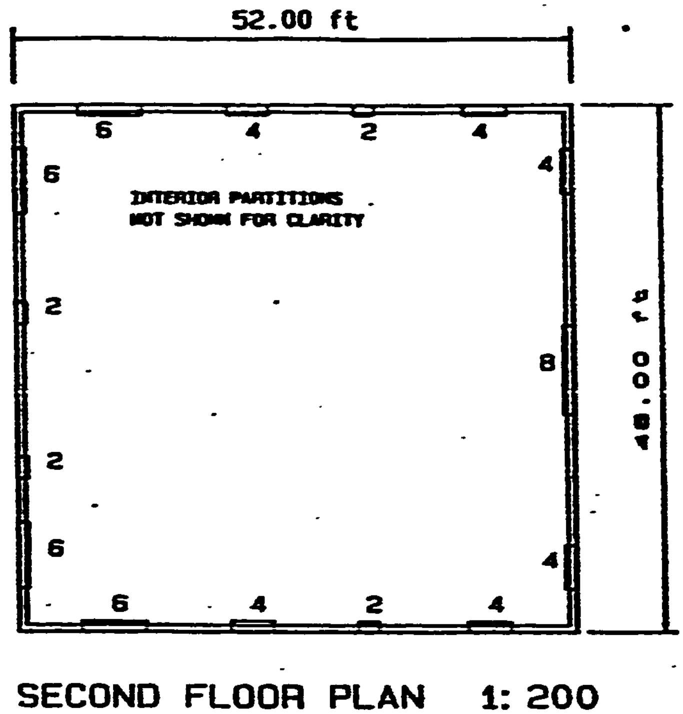
The villa's architectural parameters are as follows [17]:

Total gross floor area (two floors)	= 5070 sq ft.
Gross floor area (each floor)	= 2535 sq ft.
Number of stories	= 2.
Overall height	= 19.5 ft.
Floor-to-floor height	= 9.75 ft.
Plan shape	= rectangular (close to

square).

Width (side to side)	= 52 ft.
Depth (front to back)	= 48 ft.
Gross exterior wall area	= 3900 sq ft (1950/floor).
Window area	= 10% of gross floor area (512 sq ft total) (256 sq ft per floor).
Window distribution	= uniformly distributed on all four sides of the building (64 sq ft per side per floor in real size windows).
Orientation	= random (south assumed).

The diagrammatic plans and elevations for the typical Saudi villa are shown in Figures 3.1 and 3.2 [17].



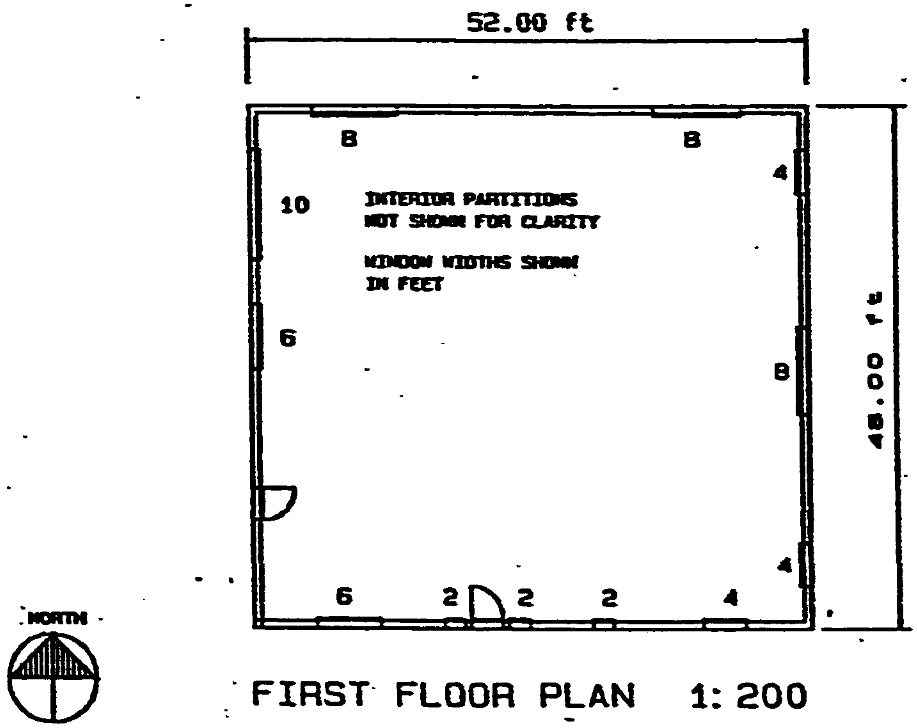


Figure 3.1: Typical Saudi villa floor plans [17].

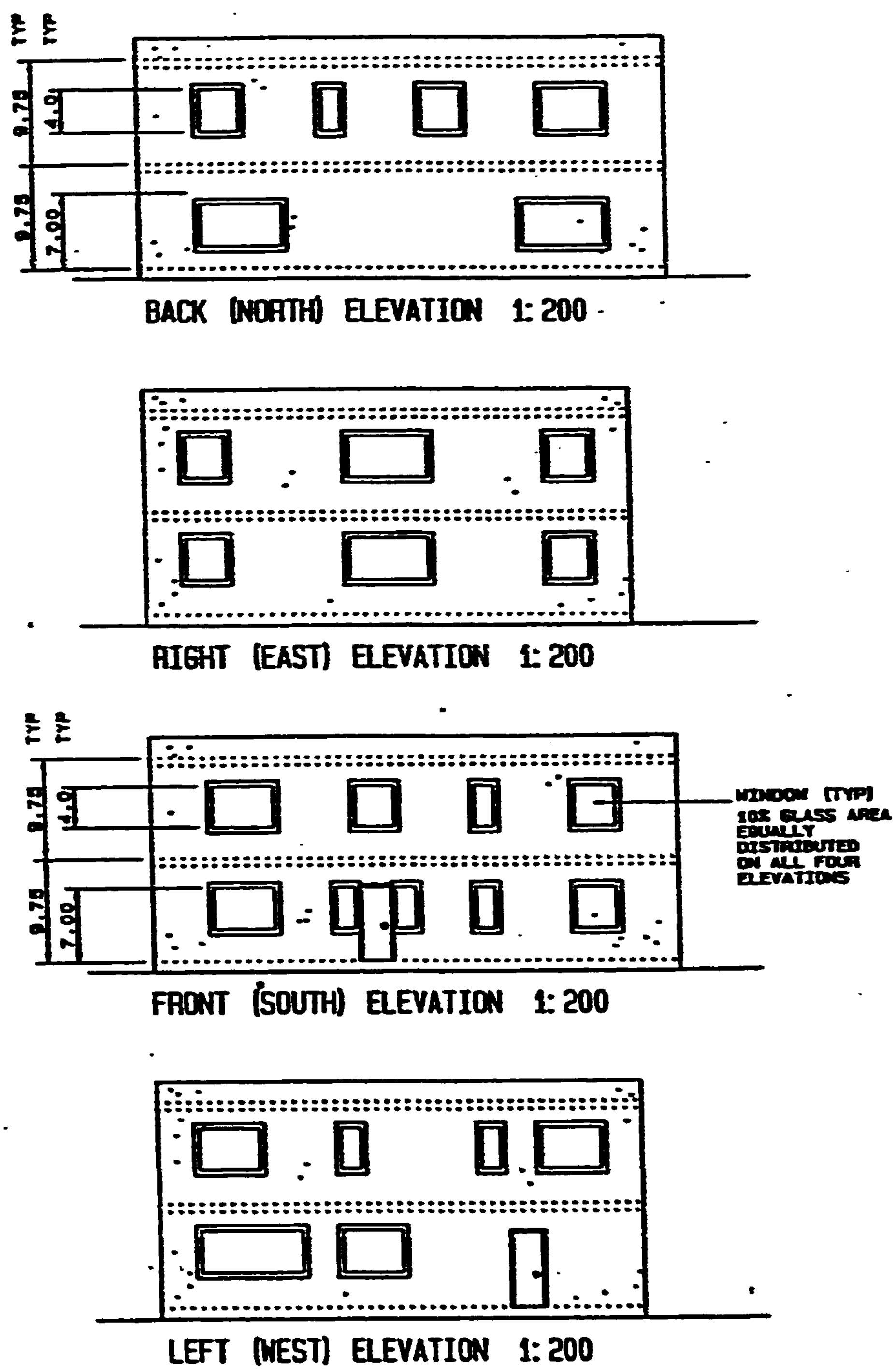


Figure 3.2: Typical Saudi villa elevations [17].

3.3 Building Loads and Systems Description

As mentioned in section 5.1 of this thesis, the function of the loads module is to simulate the building envelope and internal heat flows. This process is done to calculate all cooling and heating loads, which are then passed to the systems module. The loads module requires the use of the BDL processor with a weather file. The DOE-2.1C BDL format in the input file could be seen in the simulation input file shown in Appendix D. The process of the BDL file is described in section 5.2.

The walls and roofs variations to be considered for energy simulation studies on villas are shown in Table 3.1. Table 3.2 shows a list for the thermal materials which are used as the walls and roofs components. The thermal properties of the materials used as the walls and roofs components are shown in Table 3.3.

Table 3.1: Walls and roofs variations

[17].

ID CODE		GENERAL DESCRIPTION	INSULATION CONFIGURATION
WALLS ----			
W1-1		Basic wall Number 1	uninsulated CMU - reference
W2-1		Basic wall Number 2	50 mm polystyrene - interior
W2-2		Ins. thick. variant	25 mm polystyrene - interior
W2-3		Ins. thick. variant	75 mm polystyrene - interior
W2-4		Ins. thick. variant	100 mm polystyrene - interior
W3-1		Basic wall Number 3	vermiculite filled CMU
W4-1		Basic wall Number 4	50 mm fiberglass - interior
W4-2		Ins. thick. variant	25 mm fiberglass - interior
W4-3		Ins. thick. variant	75 mm fiberglass - interior
W4-4		Ins. thick. variant	100 mm fiberglass - interior
W5-1		Basic wall Number 5	50 mm polystyrene - exterior
W5-2		Ins. thick. variant	25 mm polystyrene - exterior
W5-3		Ins. thick. variant	75 mm polystyrene - exterior
W6-1		Basic wall Number 6	50 mm polyurethane - exterior
W6-2		Ins. thick. variant	25 mm polyurethane - exterior
W6-3		Ins. thick. variant	75 mm polyurethane - exterior
W6-4		Ins. locat. variant	50 mm polyurethane - interior
W6-5		Ins. thick. variant	25 mm polyurethane - interior
W6-6		Ins. thick. variant	75 mm polyurethane - interior
W6-7		Ins. thick. variant	100 mm polyurethane - interior
W7-1		Basic wall Number 7	50 mm polystyrene - exterior
W7-2		Ins. locat. variant	50 mm polystyrene - interior
W8-1		Basic wall Number 8	50 mm polystyrene - exterior
W8-2		Ins. locat. variant	50 mm polystyrene - interior
W8-3		Construction variant	add airspace to W8-2
W9-1		Basic wall Number 9	50 mm polystyrene - exterior
W9-2		Uninsulated variant	no insulation
W9-3		Ins. locat. variant	50 mm polystyrene - interior
W10-1	(WA-1)	Basic wall Number 10	50 mm glass fiber - exterior with reflective airspace
W10-2	(WA-2)	Uninsulated variant	no insulation
W10-3	(WA-3)	Ins. locat. variant	50 mm glass fiber - interior
W10-4	(WA-4)	Construction variant	50 mm glass fiber - exterior with no reflective airspace

Table 3.1 (continued).

ID CODE		GENERAL DESCRIPTION	INSULATION CONFIGURATION
W11-1	(WB-1)	Basic wall Number 11	50 mm polystyrene - exterior
W11-2	(WB-2)	Uninsulated variant	no insulation
W11-3	(WB-3)	Ins. Locat. variant	50 mm polystyrene - interior
W12-1	(WC-1)	Basic wall Number 12	50 mm polystyrene - interior
W12-2	(WC-2)	Uninsulated variant	no insulation
W13-1	(WD-1)	Basic wall Number 13	100 mm glass fiber batt
W13-2	(WD-2)	Ins. thick. variant	150 mm glass fiber batt
W13-3	(WD-3)	Uninsulated variant	no insulation
W14-1	(WE-1)	Basic wall Number 14	50 mm polystyrene - cavity
W14-2	(WE-2)	Ins. thick. variant	no insulation
W14-3	(WE-3)	Ins. thick. variant	25 mm polystyrene - cavity
W14-4	(WE-4)	Ins. thick. variant	75 mm polystyrene - cavity
ROOFS ----			
R1-1		Basic roof Number 1	uninsulated slab - reference
R2-1		Basic roof Number 2	75 mm polystyrene - exterior
R2-2		Ins. thick. variant	25 mm polystyrene - exterior
R2-3		Ins. thick. variant	50 mm polystyrene - exterior
R2-4		Ins. thick. variant	100 mm polystyrene - exterior
R2-5		Ins. mater. variant	75 mm expnd plysty - exterior
R2-6		Ins. thick. variant	25 mm expnd plysty - exterior
R2-7		Ins. thick. variant	50 mm expnd plysty - exterior
R2-8		Ins. thick. variant	100 mm expnd plysty - exterior
R3-1		Basic roof Number 3	75 mm polyurethane - exterior
R4-1		Basic roof Number 4	75 mm polystyrene - IRMA
R4-2		Construction variant	R4-1 without mortar
R4-3		Construction variant	R4-1 without mortar and sand
R5-1		Basic roof Number 5	75 mm polystyrene - interior
R5-2		Ins. thick. variant	25 mm polystyrene - interior
R5-3		Ins. thick. variant	50 mm polystyrene - interior
R5-4		Ins. thick. variant	100 mm polystyrene - interior
R6-1		Basic roof Number 6	uninsulated Hourdi - reference
R7-1		Basic roof Number 7	75 mm expnd plysty- exterior
R7-2		Ins. thick. variant	25 mm expnd plysty- exterior
R7-3		Ins. thick. variant	50 mm expnd plysty- exterior
R7-4		Ins. thick. variant	100 mm expnd plysty- exterior

Table 3.1 (continued).

ID CODE		GENERAL DESCRIPTION	INSULATION CONFIGURATION
R8-1		Basic roof Number 8	100 mm glass fiber batt-interior
R8-2		Ins. thick. variant	75 mm glass fiber batt -interior
R8-3		Ins. thick. variant	150 mm glass fiber batt-interior
R8-4		Uninsulated variant	no insulation
R9-1		Basic roof Number 9	75 mm polystyrene - exterior
R9-2		Ins. thick. variant	100 mm polystyrene - exterior
R9-3		Uninsulated variant	no insulation
R10-1	(RA-1)	Basic roof Number 10	75 mm polystyrene - exterior
R10-2	(RA-2)	Uninsulated variant	no insulation
R10-3	(RA-3)	Ins. thick. variant	50 mm polystyrene - exterior
R11-1	(RB-1)	Basic roof-ltwt conc	75 mm polystyrene - exterior
R11-2	(RB-2)	Uninsulated variant	no insulation
R11-3	(RB-3)	Ins. thick. variant	50 mm polystyrene - exterior

NOTE: Ins. thick. = insulation thickness variation.
Ins. locat. = insulation location variation.
For walls:
polystyrene = expanded polystyrene.
For roofs:
polystyrene = extruded polystyrene.
expnd plysty = expanded polystyrene.

Table 3.2: Thermal materials list

ID Code	General Material Description
A1	Outside air film -- vertical or horizontal
A2	Inside air film -- vertical (horizontal heat flow) non-reflective
A3	Inside air film -- horizontal (downward heat flow) non-reflective
A4	13 mm air space -- vertical (horizontal heat flow) non-reflective
A4A	13 mm air space -- vertical (horizontal heat flow) one surface reflective
A5	50 mm air space -- vertical (horizontal heat flow) non-reflective
A6	100 mm air space -- horizontal (downward heat flow) non-reflective
A7	250 mm air space -- horizontal (downward heat flow) non-reflective
A8	100 mm air space -- vertical (horizontal heat flow) non-reflective
A9	200 mm air space -- horizontal (downward heat flow) non-reflective
M1	13 mm Portland cement plaster
M1A	M1 -- applied to metal lath
M2	16 mm Portland cement stucco
M2A	M2 -- applied to metal lath
M3	200 mm cored concrete masonry unit
M4	M3 -- with vermiculite fill in cores
M5	200 mm split-face cored concrete masonry unit

Table 3.2 (continued).

ID Code	General Material Description
M6	100 mm cored concrete masonry unit
M7	200 mm hollow clay tile
M8	100 mm sand-lime brick
M9	250 mm reinforced concrete slab
M10	250 mm Hourdi-block concrete slab
M11	200 mm precast cored plank
M12	25 mm terrazzo tile
M13	20 mm marble facing
M14	20 mm mortar bed
M15	20 mm sand fill
M16	250 mm reinforced lightweight concrete slab
P1	13 mm gypsum wallboard
P2	20 gage metal decking (steel)
W1	EDP waterproofing membrane
I1	25 mm expanded polystyrene insulation board
I2	50 mm expanded polystyrene insulation board
I3	75 mm expanded polystyrene insulation board
I31	100 mm expanded polystyrene insulation board
I4	25 mm extruded polystyrene insulation board
I5	50 mm extruded polystyrene insulation board
I6	75 mm extruded polystyrene insulation board
I7	100 mm extruded polystyrene insulation board

Table 3.2 (continued).

ID Code	General Material Description
I8	25 mm polyurethane insulation board
I9	50 mm polyurethane insulation board
I10	75 mm polyurethane insulation board
I101	100 mm polyurethane insulation board
I11	25 mm glass fiber insulation board
I12	50 mm glass fiber insulation board
I13	75 mm glass fiber insulation board
I131	100 mm glass fiber insulation board
I14	75 mm glass fiber batt insulation
I15	100 mm glass fiber batt insulation
I16	150 mm glass fiber batt insulation

Table 3.3: Thermal properties of materials [17].

Material ID Code	Thickness (Feet)	Conductivity (Btu-ft / hr-sq ft-F)	Density (lb / cu ft)	Specific Heat (Btu / lb-F)
A1	data not required as input - calculated by DOE-2			
A2	NA	R = 0.68	NA	NA /1/
A3	NA	R = 0.92	NA	NA /2/
A4	NA	R = 0.77	NA	NA /3/
A4A	NA	R = 1.67	NA	NA /4/
A5	NA	R = 0.86	NA	NA /5/
A6	NA	R = 0.92	NA	NA /6/
A7	NA	R = 1.53	NA	NA /7/
A8	NA	R = 0.92	NA	NA /6/
A9	NA	R = 0.92	NA	NA /6/
M1	0.043	0.4167	116.0	0.20 /8/
M1A	0.043	0.430	116.0	0.20 /9/
M2	0.052	0.4167	116.0	0.20 /8/
M2A	0.052	0.430	116.0	0.20 /9/
M3	0.667	0.606	69.0	0.20 /10/
M4	0.667	0.2272	70.0	0.20 /11/
M5	0.750	0.606	69.0	0.20 /12/
M6	0.333	0.4694	101.0	0.20 /13/
M7	0.667	0.360	70.0	0.20 /14/
M8	0.333	0.318	104.0	0.20 /15/
M9	0.820	1.0417	140.0	0.20 /16/

Table 3.3 (continued).

Material ID Code	Thickness (Feet)	Conductivity (Btu-ft / hr-sq ft-F)	Density (lb / cu ft)	Specific Heat (Btu / lb-F)
M10	0.820	0.861	110.0	0.20 /17/
M11	0.667	0.758	81.0	0.20 /18/
M12	0.082	1.0416	140.0	0.19 /19/
M13	0.066	1.50	162.0	0.21 /20/
M14	0.066	0.4167	116.0	0.20 /21/
M15	0.066	0.190	94.6	0.191 /22/
M16	0.820	0.2083	80.0	0.20 /23/
P1	0.043	0.0926	50.0	0.20 /24/
P2	0.003	26.20	489.0	0.12 /25/
W1	0.003	0.02	70.0	0.36 /26/
I1	0.082	0.021 /27/	1.3 /28/	0.29 /29/
I2	0.164	0.021 /27/	1.3 /28/	0.29 /29/
I3	0.246	0.021 /27/	1.3 /28/	0.29 /29/
I31	0.328	0.021 /27/	1.3 /28/	0.29 /29/
I4	0.082	0.0183 /27/	1.31 /28/	0.29 /30/
I5	0.164	0.0183 /27/	1.31 /28/	0.29 /30/
I6	0.246	0.0183 /27/	1.31 /28/	0.29 /30/
I7	0.328	0.0183 /27/	1.31 /28/	0.29 /30/
I8	0.082	0.0136 /27/	2.19 /28/	0.38 /31/
I9	0.164	0.0136 /27/	2.19 /28/	0.38 /31/
I10	0.246	0.0136 /27/	2.19 /28/	0.38 /31/
I101	0.328	0.0136 /27/	2.19 /28/	0.38 /31/
I11	0.082	0.0191 /27/	3.0 /28/	0.23 /32/

Table 3.3 (continued).

Material ID Code	Thickness (Feet)	Conductivity (Btu-ft / hr-sq ft-F)	Density (lb / cu ft)	Specific Heat (Btu / lb-F)
I12	0.164	0.0191 /27/	3.0 /28/	0.23 /32/
I13	0.246	0.0191 /27/	3.0 /28/	0.23 /32/
I131	0.328	0.0191 /27/	3.0 /28/	0.23 /32/
I14	0.246	0.0266 /28/	0.63 /28/	0.20 /28/
I15	0.328	0.0266 /28/	0.63 /28/	0.20 /28/
I16	0.492	0.0266 /28/	0.63 /28/	0.20 /28/

Finally, the thermal materials layers for walls and roofs variations are shown in Table 3.4.

In modelling the heat extraction from the villa, the package single zone (PSZ) mechanical system has been selected as a type for use. The whole space of the villa has been considered as a single zone, and a range of four sizes of package single zone units has been established. The system parameters have been put into the simulation input files for the typical villa to model the energy use of the cooling equipment which is used to extract the heat loads from the building [17]. The system parameters are shown in the simulation input file in Appendix D.

Table 3.4: Thermal materials layers

[17].

ID CODE	GENERAL DESCRIPTION	THERMAL LAYERS (from Exterior to Interior)
WALLS ----		
W1-1	Wall No. 1	A1, M2, M3, M1, A2
W2-1	Wall No. 2	A1, M2, M3, I2, M1A, A2
W2-2	Thk variant	A1, M2, M3, I1, M1A, A2
W2-3	Thk variant	A1, M2, M3, I3, M1A, A2
W2-4	Thk variant	A1, M2, M3, I31, M1A, A2
W3-1	Wall No. 3	A1, M2, M4, M1, A2
W4-1	Wall No. 4	A1, M2, M3, I12, M1A, A2
W4-2	Thk variant	A1, M2, M3, I11, M1A, A2
W4-3	Thk variant	A1, M2, M3, I13, M1A, A2
W4-4	Thk variant	A1, M2, M3, I131, M1A, A2
W5-1	Wall No. 5	A1, M2A, I2, M3, M1, A2
W5-2	Thk variant	A1, M2A, I1, M3, M1, A2
W5-3	Thk variant	A1, M2A, I3, M3, M1, A2
W6-1	Wall No. 6	A1, M2A, I9, M3, M1, A2
W6-2	Thk variant	A1, M2A, I8, M3, M1, A2
W6-3	Thk variant	A1, M2A, I10, M3, M1, A2
W6-4	Loc variant	A1, M2, M3, I9, M1A, A2
W6-5	Loc variant	A1, M2, M3, I8, M1A, A2
W6-6	Loc variant	A1, M2, M3, I10, M1A, A2
W6-7	Loc variant	A1, M2, M3, I101, M1A, A2
W7-1	Wall No. 7	A1, M13, I2, M3, M1, A2
W7-2	Loc variant	A1, M13, M3, I2, M1A, A2
W8-1	Wall No. 8	A1, M8, I2, M3, M1, A2
W8-2	Loc variant	A1, M8, M3, I2, M1A, A2
W8-3	Con variant	A1, M8, A4, M3, I2, M1A, A2
W9-1	Wall No. 9	A1, M2A, I2, M7, M1, A2
W9-2	Thk variant	A1, M2, M7, M1, A2
W9-3	Loc variant	A1, M2, M7, I2, M1A, A2

Table 3.4 (continued).

ID CODE	GENERAL DESCRIPTION	THERMAL LAYERS (from Exterior to Interior)
W10-1 (WA-1)	Wall No.10	A1, M8, A4A, I12, M3, M1, A2
W10-2 (WA-2)	Thk variant	A1, M8, A4, M3, M1, A2
W10-3 (WA-3)	Loc variant	A1, M8, A4, M3, I12, M1A, A2
W10-4 (WA-4)	Con variant	A1, M8, A4, I12, M3, M1, A2
W11-1 (WB-1)	Wall No. 11	A1, M8, I2, M7, M1A, A2
W11-2 (WB-2)	Thk variant	A1, M8, M7, M1, A2
W11-3 (WB-3)	Loc variant	A1, M8, M7, I2, M1A, A2
W12-1 (WC-1)	Wall No. 12	A1, M5, I2, M1A, A2
W12-2 (WC-2)	Thk variant	A1, M5, M1, A2
W13-1 (WD-1)	Wall No. 13	A1, M2A, P1, I14, P1, A2
W13-2 (WD-2)	Thk variant	A1, M2A, P1, I15, P1, A2
W13-3 (WD-3)	Thk variant	A1, M2A, P1, A8, P1, A2
W14-1 (WE-1)	Wall No. 14	A1, M2, M6, I2, M6, M1, A2
W14-2 (WE-2)	Thk variant	A1, M2, M6, A5, M6, M1, A2
W14-3 (WE-3)	Thk variant	A1, M2, M6, I1, M6, M1, A2
W14-4 (WE-4)	Thk variant	A1, M2, M6, I3, M6, M1, A2
ROOFS ---		
R1-1	Roof No.1	A1, M12, M14, M15, W1, M9, M1, A3
R2-1	Roof No. 2,	A1, M12, M14, M15, W1, I6, M9, M1, A3
R2-2	Thk variant	A1, M12, M14, M15, W1, I4, M9, M1, A3
R2-3	Thk variant	A1, M12, M14, M15, W1, I5, M9, M1, A3
R2-4	Thk variant	A1, M12, M14, M15, W1, I7, M9, M1, A3
R2-5	Mat variant	A1, M12, M14, M15, W1, I3, M9, M1, A3
R2-6	Thk variant	A1, M12, M14, M15, W1, I1, M9, M1, A3
R2-7	Thk variant	A1, M12, M14, M15, W1, I2, M9, M1, A3
R2-8	Thk variant	A1, M12, M14, M15, W1, I31, M9, M1, A3
R3-1	Roof No. 3	A1, M12, M14, M15, W1, I10, M9, M1, A3
R4-1	Roof No. 4	A1, M12, M14, M15, I6, W1, M9, M1, A3
R4-2	Con variant	A1, M12, M15, I6, W1, M9, M1, A3
R4-3	Con variant	A1, M12, I6, W1, M9, M1, A3
R5-1	Roof No. 5	A1, M12, M14, M15, W1, M9, I6, M1A, A3
R5-2	Thk variant	A1, M12, M14, M15, W1, M9, I4, M1A, A3
R5-3	Thk variant	A1, M12, M14, M15, W1, M9, I5, M1A, A3
R5-4	Thk variant	A1, M12, M14, M15, W1, M9, I7, M1A, A3

Table 3.4 (continued).

ID CODE	GENERAL DESCRIPTION	THERMAL LAYERS (from Exterior to Interior)
R6-1	Roof No. 6	A1, M12, M14, M15, W1, M10, M1, A3
R7-1	Roof No. 7	A1, M12, M14, M15, W1, I3, M10, M1, A3
R7-2	Thk variant	A1, M12, M14, M15, W1, I1, M10, M1, A3
R7-3	Thk variant	A1, M12, M14, M15, W1, I2, M10, M1, A3
R7-4	Thk variant	A1, M12, M14, M15, W1, I31, M10, M1, A3
R8-1	Roof No. 8	A1, M12, M14, M15, W1, M10, A6, I15, M1A, A3
R8-2	Thk variant	A1, M12, M14, M15, W1, M10, A6, I14, M1A, A3
R8-3	Thk variant	A1, M12, M14, M15, W1, M10, A6, I16, M1A, A3
R8-4	Thk variant	A1, M12, M14, M15, W1, M10, A9, M1A, A3
R9-1	Roof No. 9	A1, W1, I6, P2, A7, P1, A3
R9-2	Thk variant	A1, W1, I7, P2, A7, P1, A3
R9-3	Thk variant	A1, W1, P2, A7, P1, A3
R10-1 (RA-1)	Roof No. 10	A1, M12, I6, W1, M11, M1, A3
R10-2 (RA-3)	Thk variant	A1, M12, W1, M11, M1, A3
R10-3 (RA-3)	Thk variant	A1, M12, I5, W1, M11, M1, A3
R11-1 (RB-1)	Lt.Wt. Conc.	A1, M12, M14, M15, W1, I6, M16, M1, A3
R11-2 (RB-2)	Thk variant	A1, M12, M14, M15, W1, M16, M1, A3
R11-3 (RB-3)	Thk variant	A1, M12, M14, M15, W1, I5, M16, M1, A3

NOTE: Thk variant = variation of insulation thickness
Loc variant = variation of insulation location
Con variant = variation of construction approach
Mat variant = variation of insulation material

3.4 Wall and Roof Configurations

In order to simulate as much as possible buildings types and constructions, different wall and roof configurations were selected. "The basic premise of the selection process was that the panels selected should be representative of Saudi Arabian construction or show promise as an alternative to current construction practices [9]." This premise applies primarily to the basic construction techniques selected rather than to insulation approaches because the majority of construction in the Kingdom is not insulated. Furthermore, the selection of the insulation materials was based upon manufacture or availability in the Kingdom.

For wall and roof situations, the panel selections basically consisted of one reference construction which represented current construction practices. A variety of modifications to the reference cases which represented different approaches to providing an insulated construction are presented as alternatives to more traditional construction techniques [9]. The fourteen base walls and the ten base roofs configurations are presented in Appendix C.

Chapter 4
MODELS FOR INSULATION ECONOMICS

4.1 Description of the Available Models

In order to select a simulation model among some alternatives, we have to set our objectives and then select the model which meets the objectives we set. The economic simulation model we use has to meet the economic parameters of this research. These economic parameters are [18]:

1. Economic parameters associated with energy:
    a. Energy cost in terms of electricity.
    b. Capital investment in air conditioning and/or heating equipment with distribution system to point of use.
    c. Depreciation period.
    d. Maintenance cost (yearly).
2. Economic parameters associated with installing the insulation:
    a. Capital investment for insulation of a given thickness, including material costs and labor costs for installing the material.

b. Depreciation period (years).

c. Salvage value.

Among many economic simulation models, three models were selected to be analyzed in order to get the best model to be used. These three models were selected because of their reliability and because they have been used and tested by some neighboring countries which have almost the same conditions as Saudi Arabia. These three economic simulation models are:

1. **Model 1:** An economic simulation model developed by Fereig and Younis [19].
2. **Model 2:** An economic simulation model used by the Ministry of Electricity and Water in the State of Kuwait [12].
3. **Model 3:** The DOE-2 economic simulation model [20].

4.1.1 Model 1

This model was used by S.M. Fereig and M.A. Younis in a study they had made on the effects of energy conservation measures on the life cycle cost of Kuwaiti residential buildings [19].

The purpose of life cycle costing is to determine the expenses associated with various design alternatives using the concept of equivalent cost. These expenses include:

1. Cost of acquisition,
2. Yearly operating and maintenance costs,
3. Yearly fuel and utility costs,
4. Future repairs and alterations, and
5. Future replacement of major systems.

In order to compare between different alternatives, this model calculates the equivalent uniform annual cost (EUAC) for each alternative. "The EUAC is a constant annual amount which, if paid throughout the assumed life cycle of the building, equals the discounted total life costs [19]." In order to simplify the comparison of alternatives, the EUAC converts an uneven stream of expenditures, which occur over a number of years, into a constant annual amount.

EUAC is expressed mathematically as follows [19]:

$$EUAC = CR\{(I)(PV) + \sum_{a=1}^{n} (PV_a) \times (R + O_a E_a + M_a) + S(PV)\}$$

where,

EUAC = Equivalent uniform annual cost.

CR = Capital recovery factor.

PV = Present value factor.

I = Initial costs of development, design, and construction.

$\sum_{a=1}^{n}$ = The sum as 'a' varies from a=1 to the end of the building life cycle, 'n'.

a = Number of the year. It varies from 1 to n.

R = Cost of replacing building components during the building's life cycle.

O_a = Annual operating cost (Kuwaiti dinars) for the a^{th} year in the base year.

E_a = Differential escalator for the a^{th} year to adjust utility cost for future rises in price greater than the general price level.

M_a = Annual maintenance cost (K.D.) for the a^{th} year in the base year which is taken as a ratio of the equipment cost.

S = Salvage value of the building and land at the end of the building's assumed life cycle.

Thus, "EUAC is obtained by multiplying the costs of each year of ownership by the present value factor, summing these to reach the present value of the total life cycle cost, and then multiplying this value by the capital recovery factor [19]."

'CR' is mathematically expressed as:

$$CR = \frac{i(1+i)^n}{(1+i)^n - 1}$$

where:

i = Discount rate, and

n = Number of years.

This capital recovery factor is calculated to convert a one-time cost investment into an equivalent uniform cash flow, at a specific discount rate for a certain number of years.

'PV' is mathematically expressed as:

$$PV = \frac{1}{(1 + i)^n}$$

In this model, the discount rate of return, represents an estimate of the average rate of return on private investment before taxes and after inflation.

In order to get the EUAC for different alternatives, the required data for the life cycle cost analysis are:

1. Building's economic life,
2. Air conditioning economic life,
3. Project discount rate,
4. Calculated peak cooling load,
5. Coefficient of performance of the air conditioning unit,
6. Air conditioning unit required KW at design load, and

7. Calculated yearly consumption.

To get the LCC estimates, four cost elements are to be estimated first. These are:

1. Initial:

    * Additional cost for exterior closure due to energy measures,
    * Additional roofing cost due to energy measure, and
    * Heating and ventilation, and air conditioning cost.

2. Operating costs:

    * Heating, ventilation, air conditioning, and energy costs.

3. Maintenance:

    * Repairs and routine replacements.

4. Replacements:

    * Air conditioning unit every 10 years.

In the life cycle cost analysis, identical costs for alternatives are ignored. "The only costs included in the analysis are the significant, different costs of alternatives that could influence their ranking [19]." Thus, as all the variables are obtained, the EUAC for each design alternative could be calculated.

4.1.2 Model 2

This economic simulation model was used by the Ministry of Electricity and Water in the State of Kuwait in its energy conservation program for residential sector buildings [12]. In this model, three different performance indices are computed.

4.1.2.1 Customer Performance Index (CPI)

"This index corresponds to the net discounted savings for the customer over a discount period of 'n' years [12]."

This index is defined as follows:

CPI = Discounted value of saved energy and
saved maintenance costs over the
period of 'n' years.
− Net initial investment by customer.

where,
net initial investment by customer =
{ Cost of conservation measures }
− { Cost of reduction in air-conditioning
+ Capacity savings in electrical supply
fees }.

and,
Cost of conservation measures =
Wall insulation cost + Roof insulation cost
+ Floor insulation cost
+ Window treatment cost
+ Air infiltration control cost
+ VAV system cost.

The discounted value of saved energy and saved
maintenance costs over the period of 'n' years =
'n' × Total annual savings.

Where,

Total annual savings = Annual cost of saved energy
+ Annual cost of saved
maintenance.

$$\textit{Return on investment} = \frac{\textit{Total annual savings}}{\textit{Net initial investment}} \times 100$$

4.1.2.2 Government Performance Index (GPI)

This index corresponds to the benefits the Ministry of Electricity and Water will gain from energy conservation over the specified discount period [12]. It consists of the following:

GPI = Net savings due to reduced electric generating capacity
+ Value of subsidy on saved energy over the discount period.

Where,
Value of subsidy on saved energy over the discount period 'n' =
'n' × Annual subsidy savings.

4.1.2.3 National Performance Index (NPI)

This index reflects the net benefits to the country during the discount period, resulting from the various energy conservation measures [12].

This index consists of the following:

NPI = Net savings due to reduced electric generating capacity
− Cost of energy conservation measures
+ Savings in reduced air-conditioning capacity
+ Value of saved energy at real cost and saved maintenance costs over the discount period.

"Because of the comprehensive nature of this national index, it is used to select optimum conservation measures. This is done by determining R-values (insulation levels) of insulation added to roofs, walls, and floors, as well as glazing types, which will maximize the NPI [12]."

4.1.3 Model 3

This economic simulation model is known as the DOE-2, which is the second version of DOE (Department of Energy) versions. In DOE-2, cost calculations are made in two different programs, the PLANT and the ECONOMICS.

The PLANT program calculates energy costs and plant equipment capital and operating costs. PLANT passes the following data to ECONOMICS [20]:

1. Discount rate (%),
2. Labor inflation rate (%),
3. Materials inflation rate (%),
4. Project lifetime (years),
5. Labor cost ($/hour),
6. Plant equipment cost ($),
7. Life-cycle cost for replacing plant equipment ($),
8. Annual energy use at the site (Btu),

9. Annual energy use at the source (Btu),
10. Present value of energy cost for each year of the project lifetime ($), and
11. Present value of plant operating costs for each year of the project lifetime ($).

The ECONOMICS program calculates costs for nonplant components, which include secondary systems, insulation, control systems, solar collectors, and others. Nonplant costs will be referred to as 'building costs'. ECONOMICS adds plant costs to building costs and arrives at an overall life-cycle cost. It also computes the following economic measures or what are known as 'investment statistics':

1. Investment.
2. Energy and non-energy cost savings.
3. Energy use savings.
4. Ratio of total cost savings to investment.
5. Ratio of energy use savings to investment.
6. Discounted payback period.

These quantities are calculated by comparing costs and energy use for each alternative under analysis with those entered by the user for a baseline case.

In the DOE-2 life-cycle cost calculations, the project lifetime is defined as the period, in years, over which the life-cycle cost analysis is made, which in the DOE-2 can be between 1 and 25 years. The life-cycle cost is defined as the total cost of an item over the project lifetime [20].

The life-cycle cost (LCC) for a cost that recurs every year, such as energy cost, is:

$$LCC = \sum_{n=1}^{N} C_n$$

Where,

N = The project lifetime, and

C^n = The cost in the n*th* year.

Rather than using the actual cost in year 'n', the program calculates the present value of the cost, which is given by:

$$C_n(\textit{Present value}) = C\left(\frac{1+i}{1+d}\right)^n$$

Where,

C = The cost in current dollars,

i = The cost inflation rate (relative to general inflation),

d = The discount rate.

In DOE-2, non-energy costs are divided into three categories:

1. First cost: The purchase price of an item, including installation.
2. Operations cost: Includes expenses, such as maintenance and overhauls required to keep the item in working condition.
3. Replacement cost: The capital cost, including installation, of replacing an item at the end of its useful life.

The residual value, which is the fraction of remaining useful life times the capital cost of the item at the end of the analysis period, is not considered in DOE-2.

The primary application of DOE-2 model is cost-benefit analysis of energy conservation projects (ENCOP's). In such analysis, a baseline building is first analyzed in order to determine its costs and energy use. Next, the building is modified to conserve energy and is run through DOE-2 again.

The quantities that enter the cost effectiveness analysis are:

1. Investment:

   ENCOP investment = First cost + Replacement costs for all components.

2. Incremental investment:

   Incremental investment = (ENCOP investment) − (Baseline replacement cost).

3. Cost savings:

$$\text{Cost savings} = (\text{Energy cost} + \text{Operations cost})_{baseline} - (\text{Energy cost} + \text{Operations cost})_{ENCOP}$$

4. Energy savings:

   In DOE-2, the energy use is calculated both at site and at the source, and the energy savings for both cases are calculated in ECONOMICS.

5. Savings-to-investment ratio (SIR):

$$SIR = \frac{\textit{Cost savings}}{\textit{Incremental investment}}$$

6. Energy savings to investment ratio:

$$\textit{Energy savings investment ratio} = \frac{\textit{Energy savings}}{\textit{Incremental investment}}$$

7. Discounted payback period:

   This is the number of years it takes the accumulated cost savings of the building to equal the incremental investment. For a cost-effective ENCOP, the payback period is less than the project lifetime.

Table 4.1 breaks down the three economical model into their components.

Table 4.1: Components of the economical models.

Model	Economic Analysis Used	Elements of Model	Economical Parameters					
			Wall Insulation	Roof Insulation	A/C Cost	Energy Cost	Maintenance Cost	Electricity Savings
FEREIG'S MODEL	Annual Worth Method	Government EUAC				Energy Cost		
		Customer's EUAC	Wall Insulation	Roof Insulation	A/C System Cost	Energy Cost	Maintenance Cost	
KUWAITI MODEL	Present Worth Method	CPI	(-) Wall Insulation	(-) Roof Insulation	Cost Of Reduction In A/C	Cost Of Saved Energy	Cost Of Saved Maintenance	Capacity Savings In Electrical Supply Fees
		GPI				Cost Of Saved Energy		Cost Of Reduction In Electrical Generating Capacity Savings
		NPI	(-) Wall insulation	(-) Roof insulation	Cost Of Reduction In A/C	Cost Of Saved Energy (For Both Government And Customer)	Cost Of Saved Maintenance	Cost Of Reduction In Electrical Generating Capacity Savings
DOE MODEL	Present Worth Method	Cost Savings	Wall Insulation	Roof Insulation	A/C System Cost	Energy Cost	Maintenance Cost	

1: EUAC = Equivalent Uniform Annual Cost.
2: CPI = Customer's Performance Index.
3: GPI = Government Performance Index.
4: NPI = National Performance Index.

4.2 Models Evaluation

As shown in Table 4.1, Fereig's model uses annual worth method, which is easy to understand, while the other two models use the present worth method. While both Fereig's and Kuwaiti models calculate the savings for both the government and the customer, the DOE model does not calculate the savings for the government. The major limitation of the DOE model is that it is built for the United States' economic conditions, and the costs are in dollars.

Due to the mentioned factors, in addition to the fact that both Fereig's and the Kuwaiti models have been used by a Gulf country which has similar economic and climatic conditions as Saudi Arabia, either one, with some modifications, can be used as an economic model for our project.

Fereig's model uses the annual worth method (the Equivalent Uniform Annual Cost). This will ease the comparison of the annual savings for both the customer and the government with other alternatives. Thus, Fereig's model will be used in this project for the economic studies. Table 4.2 summarizes the evaluation of the three models.

Table 4.2: Evaluation of the economical models

Model	Economical Method Used	Evaluation
FEREIG'S MODEL	Annual Worth Method	ADVANTAGES: * Annual costs are easier for comparison. * The model is clear and step forward. * It calculates savings for both customer and government. * It has been used in a Gulf country. DISADVANTAGES: * It does not include the capacity savings in electrical supply fees for the customer. * It does not include the cost of reduction in electrical generating capacity savings.
KUWAITI MODEL	Present Worth Method	ADVANTAGES: * It has been used in a Gulf country. * It calculates savings for the customer, the government, and the national. * It includes the capacity savings in electrical supply fees for the customer. * It includes the cost of reduction in the electrical generating capacity savings. DISADVANTAGES: * Present value is not as clear as annual value, specially for energy and maintenance.
DOE-2 MODEL	Present Worth Method	DISADVANTAGES: * Present value is not as clear as annual value. * It does not calculate the government's savings. * It does not include the capacity savings in electrical supply fees for the customer. * It is built for the United States economical conditions. * Calculated costs are in dollars.

To modify the Fereig's model to include all relative costs associated with energy cost savings, the following will be done:

1. For customer's EUAC, the economic parameter of capacity savings in electrical supply fees will be added. Thus, the modified Fereig's customer's EUAC will become as:

```
Customer's EUAC = Wall insulation
                + Roof insulation
                + A/C system cost
                + Energy cost
                + Maintenance cost
                + Cost of electrical capacity
                  supply fees.
```

2. For the government's EUAC, the cost of electrical generating capacity will be added. Thus, the modified Fereig's model for calculating the government's EUAC will become as:

```
Government's EUAC = Energy cost
                  + Cost of electrical
                    generating capacity.
```

4.3 Quantification of the Economic Parameters

The modified Fereig's model will be utilized for the economic analysis in this study.

Example:

The following is a sample of economic analysis using the modified Fereig's model and using a 50mm expanded polystyrene board in walls for the insulated case in Dhahran city for a discount rate of 10%. In the baseline case, wall 1-1 and roof 1-1 were used in the typical villa, while in the insulated case wall 2-1 and roof 1-1 were used. The DOE program was utilized to obtain the monthly electrical consumption and the peak load for the typical villa in Dhahran area.

Government's Equivalent Uniform Annual Cost EUAC (G):

The first economic parameter (energy cost) is calculated by multiplying the electricity consumption for the customer per month (DOE simulation report SS-A) by the subsidy that is paid by the government per month. The results are summed for the twelve months per year.

The other economic parameter (cost of electrical generating capacity) is calculated by multiplying the total peak load (converted to KW) of the villa (DOE simulation report LS-C) by the installed electric capacity cost Table 4.3.

These calculations are done separately for both baseline and insulated cases.The final government's annual savings will equal the difference between the EUAC for the two cases.

EUAC (G) = Energy cost + Cost of electrical generating capacity.

$$\text{Energy } cost_{baseline} =$$
$$= ((132503 - 48000) * 0.09) + 7800 =$$
$$= 15405.3 \text{ SR/Year}$$

$$\text{Cost of electrical generating } capacity_{baseline} =$$
$$= 5000 * 165.593 * 0.29288 =$$
$$= 242494.4 \text{ SR}$$

$EUAC\ (G)_{baseline} = 242494.4 * (A/P,10\%,25) + 15405.3 =$
$= 42120.9$ SR/Year.

Energy $cost_{insulated} =$
$= ((108810 - 48000) * 0.09 + 7800 =$
$= 13272.9$ SR/Year

Cost of electrical generating $capacity_{insulated} =$
$= 5000 * 124.257 * 0.29288 =$
$= 181961.9$ SR

$EUAC\ (G)_{insulated} = 181961.9 * (A/P,10\%,25) + 13272.9 =$
$= 33319.6$ SR/Year

Annual Government Savings = $42120.9 - 33319.6 =$
$= 8801.3$ SR/Year.

Customer's Equivalent Uniform Annual Cost EUAC (C):

The first two economic parameters (wall and roof insulation) are calculated by multiplying the summation of the insulation material's cost (Appendix A) and the installation cost (Appendix B) by the total area of the walls and roofs respectively.

The third economic parameter (A/C system cost) is calculated by multiplying the total peak load of the villa (DOE simulation report LS-C) by the A/C system cost per ton (Table 4.3) and dividing the result by 12,000 to convert the total peak load into tons. This parameter is then multiplied by the factor which converts it into annual cost.

The fourth economic parameter (energy cost) is calculated by multiplying the electricity consumption for the customer per month (DOE simulation report SS-A) by the charges per KWh paid by the customer for each month. The total energy cost per year is then calculated by summing the costs for the twelve months.

The fifth economic parameter (maintenance cost) is calculated by multiplying the total peak load for the villa (DOE simulation report LS-C) by the annual maintenance cost per ton (Table 4.3).

The last economical parameter (cost of electrical capacity supply fees) is calculated by multiplying the total peak load (converted to KW) for the villa (DOE simulation report LS-C) by the cost of electrical capacity supply fees (Table 4.3). The summation of the first two economic parameters and the last economic parameter is then multiplied by the factor which transfers this capital cost into annual cost.

The EUAC will be calculated by adding the annual costs for the economical parameters. This process is done twice for both the baseline and the insulated cases. Finally, the Customer's Annual Savings is calculated by subtracting the EUAC for the insulated case from the EUAC for the baseline case.

EUAC (C) = Wall insulation + Roof insulation + A/C system cost + Energy cost + Maintenance cost + Cost of electrical capacity supply fees.

Baseline:

Energy cost = ((132503 - 48000)* 0.15) + 3720 =
= 16395.5 SR/Year

$$\text{Maintenance cost} = 200 * \frac{165593}{12000} =$$
$$= 2759.9 \ \text{SR/Year}$$

$$\text{A/C system cost} = 3000 * \frac{165593}{12000} =$$
$$= 41398.3 \ \text{SR}$$

Cost of electrical capacity supply fees =
= 70 + (50 * 165.593 * 0.29288) =
= 2494.9 SR

$$EUAC\ (C)_{baseline} = \{(41398.3) * (A/P,10\%,10)\}$$
$$+ 16395.5 + 2759.9 + (2494.9 * i) =$$
$$= 26141.6 \ \text{SR/Year}$$

Insulated:

Energy cost = ((108810 - 48000)* 0.15) + 3720 =
= 12841.5 SR/Year

$$\text{Maintenance cost} = 200 * \frac{124,257}{12000} =$$
$$= 2071.0 \ \text{SR/Year}$$

Wall insulation cost = (10 * 314.74)+(6.25 * 314.74)
=
= 5114.5 SR

Roof insulation cost = 0 SR.

$$\text{A/C system cost} = 3000 * \frac{124257}{12000} =$$
$$= 31064.3 \text{ SR}$$

Cost of electrical capacity supply fees =
= 70 + (50 * 124.257 * 0.29288) =
= 1889.7 SR

$$\text{EUAC } (C)_{insulated} = \{(5114.5 + 0 + 1889.7) * (0.1)\} + \{(31064.3) * (A/P,10\%,10)\} + 12841.5 + 2071 =$$
$$= 20668.0 \text{ SR/Year}$$

Customer's Annual Savings = 26141.7 - 20668.0 =
= 5473.6 SR/Year

This example shows that if we use an expanded polystyrene board with a thickness of 50mm to insulate only the walls in our villa, the government will save 8801.3 SR per year, while the customer will be able to save 5473.6 SR per year.

The other economical data which will be used in the modified Fereig's model are shown in Table 4.3.

Table 4.3: Other economical costs.

Item	Cost	Comments
Air Conditioning[1]	3000 SR/Ton	Packaged air-cooled single zone (including heating and all other costs).
Maintenance cost[2]	200 SR/Ton/Year	Packaged single zone.
Installed electric capacity[3]	5000 SR/KW	Government cost (Includes transmission/distribution up to the customer).
Cost of electrical capacity supply fees[4]	<69.4 KW == 70 SR +50 SR/KW >69.4 KW == 50 SR/KW	
Electric energy[5]	0-3000 KWh == 0.07 SR/KWh 3000-4000 KWh == 0.10 SR/KWh >4000 KWh == 0.15 SR/KWh	Customer cost.
Electric energy[6]	0.24 SR/KWh	Government cost.
Discount rate		10%
Discount period[7] * A/C * Electricity transformers * Insulation materials		 10 Years. 25 Years. Building's life
Salvage value of insulation	0 SR	

1: Based on averaging of market cost for such system.
2: Based on average of maintenance for such system.
3: Refer to reference # (21).
4: Refer to reference # (22).
5: Refer to reference # (21).
6: Refer to reference # (22).
7: Based on averaging of market survey results.

Chapter 5
SIMULATION PROCESS

5.1 Introduction to the DOE-2 Program

In 1978, the original DOE-1 program was released by the Lawrence Berkeley Laboratory of The University of California for The U.S. Department of Energy. The purpose of the program is to provide a whole building energy use simulation program for use by design and research professionals. In 1979, the DOE-2 was released, and since that time a series of further updates have been released. The DOE-2.1 C program was released in 1985 and future updates are planned [9].

The DOE-2 program consists of four primary modules: the loads, systems, plan and economics modules. In addition, the program includes a building description module, a reports module and a weather processor module.

The DOE-2.1C program performs the followings:

1. Calculation of dynamic heating and cooling loads.
2. Simulation of heating and cooling systems.
3. Modeling the equipment supplying the required energy.

4. Calculation of life cycle costs of owning and operating building energy systems [23].

The building description module is used to define the building parameters of interest to the energy simulation. Such information includes description of the building envelope components, orientation data, internal load sources and operating schedule details. The building description module is also used to enter descriptions of systems and building plant components [9].

The load module calculates hourly cooling and heating loads for every space in the building. The calculation of loads precedes the application of the other modules. A very important aspect of the load calculation module is its ability to specifically model constructions which are similar in steady state analysis, but which may differ in dynamic analysis [9].

The interaction between the hourly space loads and the HVAC system delivery and control components is simulated in the systems module. A number of pre-defined systems are incorporated in the DOE-2 program and the system sizing can be performed. The output of this module is utilized by the plant module to size central plant components and determine energy consumption. A number of plant components are incorporated in the DOE-2 program. The economics module calculates the cost of energy related to the annual operation of the building as described in the program [9].

The DOE-2 weather processing module is used to edit, pack and list weather data files which are necessary for the calculation of hourly loads and equipment performance. Finally, the DOE-2 reports module is used to generate reports for a number of different loads, systems and plant variables [9].

5.2 Simulation Inputs

In order to develop comparisons among the thermal performance of the different constructions of the villa which are possible, the fourteen base walls and their additional 30 variations will be run on the DOE-2 program for each city. All other load factors, including the roof load, are kept constant. Similarly, the same method will be used for the ten base roof constructions and their 25 variations. All load factors other than the roof load, including the wall load, are kept constant [17].

For each basic construction type, different thicknesses of the given insulation material related to that type of construction have been determined for the purpose of simulation. These have been coded as wall and roof subtypes Wx-y and Rx-y (i.e., W1-2 and R2-3).

In order for the DOE-2 program to calculate the flow of heat through designated wall and roof constructions, the values for various material properties must be input to the program. A list of these materials has been shown in Tables 3.2 and 3.3 respectively.
Materials have been coded for reference as [17]:

- M for masonry building materials.
- P for panelized materials.
- I for insulation materials.
- W for waterproofing materials.
- A for air layers and films.

The BDL file starts by specifying the run-period time and describing the building location parameters, such as latitude, longitude, altitude and other related parameters. Next, the wall and roof configurations that will be applied to the villa are described. This includes all the parameters which are needed by the DOE-2 program for computations, such as the material thickness, thermal conductivity, density and specific heat. Each wall and roof configuration is described in three parts: materials, layers and constructions. Each part of these three parts is described by the earlier part [24].

Each space in the typical villa is described in terms of its area, volume, shape, width and height. Then the space is described in terms of location and construction type. Later, a single space or a group of spaces can be defined as a zone that is associated with systems.

All these data, presented in a systematic manner, create a simulation input file. An example of a simulation input file is shown in Appendix D.

5.3 Simulation Outputs

When the input simulation file is ready, it is run under the DOE-2.1C program. Hundreds of simulation runs are made (different insulated walls against a non-insulated roof, different insulated roofs against a non-insulated wall and different insulated walls against different insulated roofs) to provide a basis for the comparison of the thermal performance of the assemblies in the typical villa.

The output of the simulation runs consists of different loads and systems reports. For the purpose of the economic analysis, the following data are used [17]:

1. Total load for the villa (Report LS-C).
2. Total electrical energy (Report SS-A).

A sample of the simulation output is shown in Appendix E.

Chapter 6
RESULTS OF THE STUDY

6.1 Results Presentation

In order to give a systematic presentation of the results, each city's results will be presented separately, and then comparisons among the four cities will be given. For each city, results will be presented as follows:

1. Economic performance of walls: This will include the presentation of the annual savings for both the government and the customers for walls. Data will be presented in a table and in a bar chart for the ease of comparison among the different wall configurations. For this reason, walls have been divided into groups, where each group contains the same construction configuration with various types, thicknesses, or location of the insulation materials. In each group, a base case, no insulation, is chosen as a baseline against which all other configurations in the same group are compared. The walls have been divided into five groups, which are:

a. Concrete masonry units: This group includes wall 1 through wall 7 and wall 9. The base case for this group is wall W1-1.

b. Sandwich wall with blocks and bricks: This group includes walls 8, 10 and 11. The base case for this group is wall W10-2.

c. Split-faced block: This group includes wall 12. The base case for this group is wall W12-2.

d. Steel studs: This group includes wall 13. The base case for this group is wall W13-3.

e. Sandwich wall with blocks: This group includes wall 14. The base case for this group is wall W14-2.

2. Economic performance of roofs: This section includes the same previous information but for roofs. The roofs have been divided into six groups, as follows:

a. Reinforced concrete slab: This includes roof 1 through roof 5. The base case for this group is roof R1-1.

b. Hourdi slab: This includes roofs 6 and 7. The base case for this group is roof R6-1.

c. Hourdi slab with suspended ceiling: This group includes roof 8. The base case is roof R8-4.

d. Steel bar joist: This includes roof 9. The base case is roof R9-3.

e. Precast hollow core reinforced concrete plank: This includes roof 10. The base case for this group is roof R10-2.

f. Lightweight concrete: This includes roof 11. The base case is roof R11-2.

3. Combined performance: The main objective of our study is to find the maximum savings for both the government and the customers that could be obtained from using insulation materials both in walls and roofs. It was found that to make simulation runs for all 44 wall configurations versus 35 roof configurations, we will need a total of 1540 simulation runs for each city, which is beyond the time available for this study. Thus, it was necessary to choose a portion of the combination of walls and roofs to determine the maximum savings. The combination of concrete masonry wall with the reinforced concrete slab has been selected since both of them represent the most commonly construction configurations used in Saudi Arabia. In addition to the selection of the basic wall and roof configurations, variant insulation thicknesses from inside and outside for walls and roofs are used. These

variations are shown in Table 6.1. W1-1 represents the basic concrete masonry wall. W2-2 and W2-3 represent the W1-1 with variant thicknesses of expanded polystyrene exterior insulation. W5-1, W5-2 and W5-3 represent the W1-1 with variant thicknesses of expanded polystyrene interior insulation. Similarly, R1-1 represents the basic reinforced concrete roof. R2-1, R2-2 and R2-3 represent the R1-1 with variant thicknesses of extruded polystyrene exterior insulation. R5-1, R5-2 and R5-3 represent the R1-1 with variant thicknesses of extruded polystyrene interior insulation.

Table 6.1: Wall and Roof Configuration Combinations.

	R1-1	R2-1	R2-2	R2-3	R2-4	R5-1	R5-2	R5-3
W1-1								
W2-1								
W2-2								
W2-3								
W5-1								
W5-2								
W5-3								

During simulation runs, it was also found that the combination of a wall and a roof configuration which gives the maximum annual savings could be determined by individually obtaining the wall that gives the maximum annual savings while the roof is constant and obtaining the roof that gives maximum annual savings while the wall is constant. The only difference will be in the amount of the savings that could be achieved, which in this case, a combination case, will be higher. This is shown in Figures 6.1 through 6.8. For Dhahran city, Figure 6.1 represents the U-values and the annual savings of the concrete masonry wall with variant polystyrene board thicknesses when individually used in walls or roofs. It shows that for walls, the maximum annual saving is with an insulation thickness of 75mm. For roofs, the the maximum annual saving is with an insulation thickness of 50mm. Figure 6.2 represents the same insulation material when used in both walls and roofs simultaneously (combination) and it shows the same results as in Figure 6.1 (75mm for walls and 50mm for roofs). Figures 6.3 through 6.8 illustrate the same results for the three other cities (Riyadh, Jeddah and Khamis Mushait).

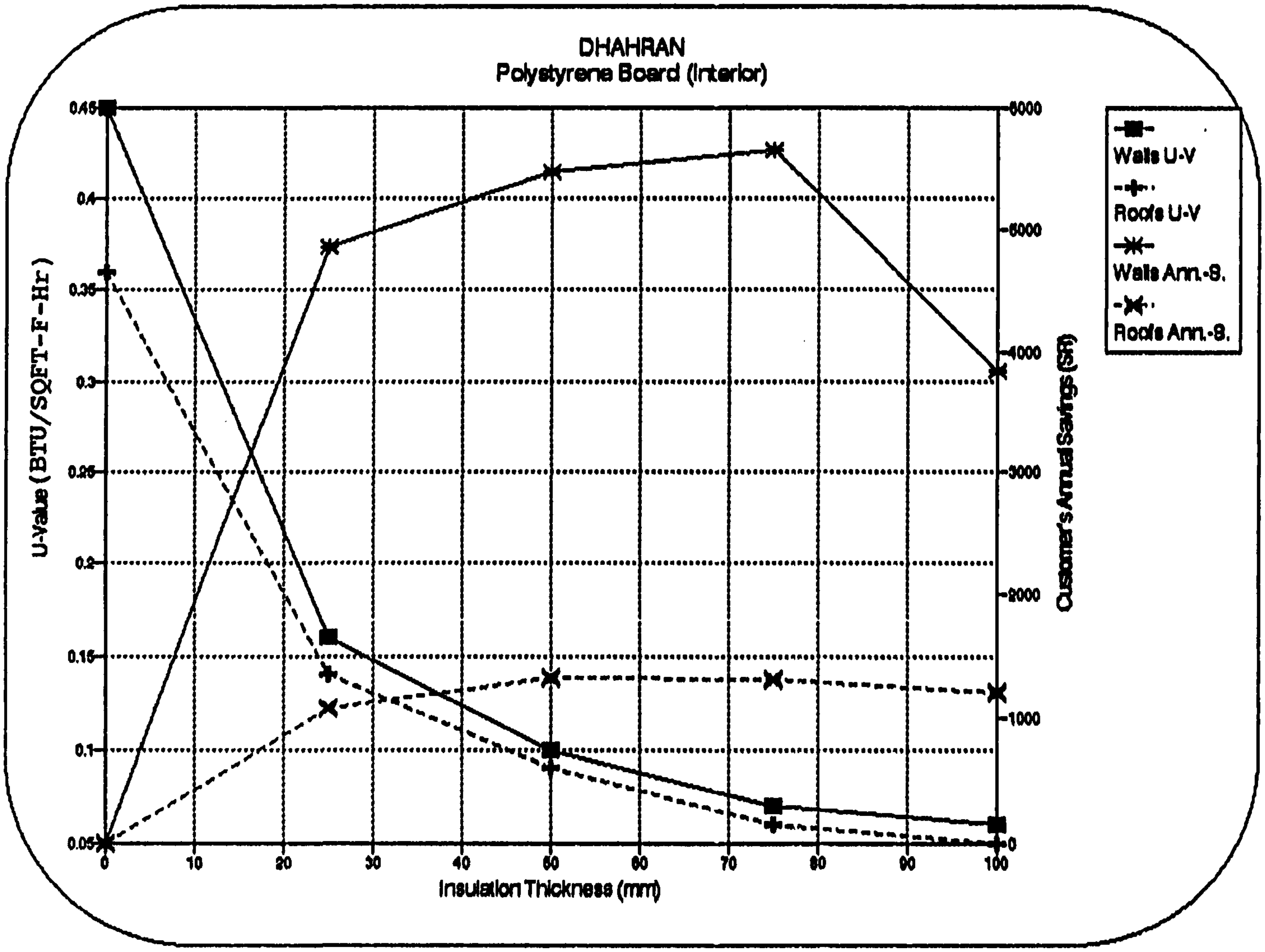


Figure 6.1: Dhahran - Polystyrene board (interior).

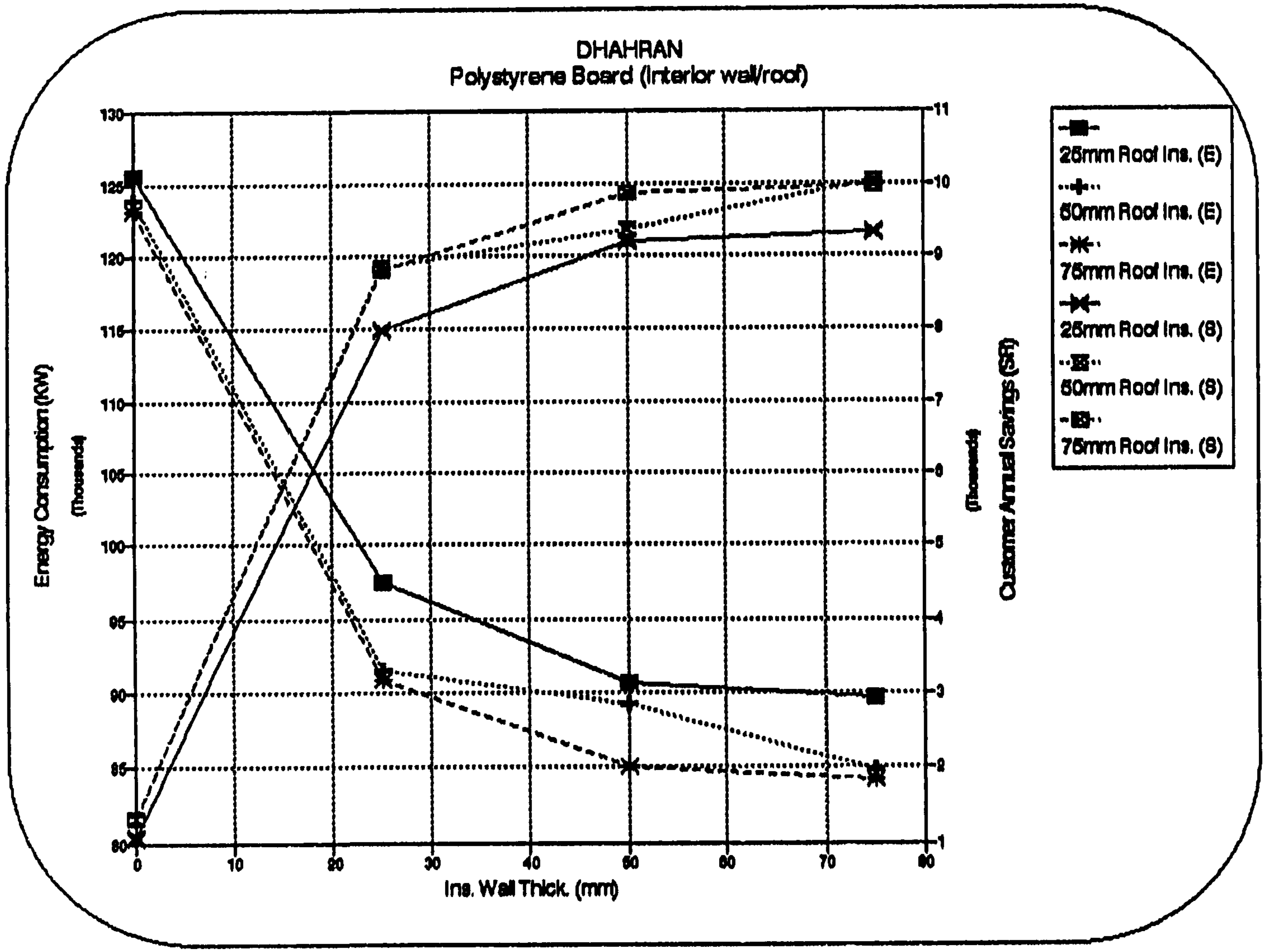


Figure 6.2: Dhahran - Polystyrene board (interior wall/ roof).

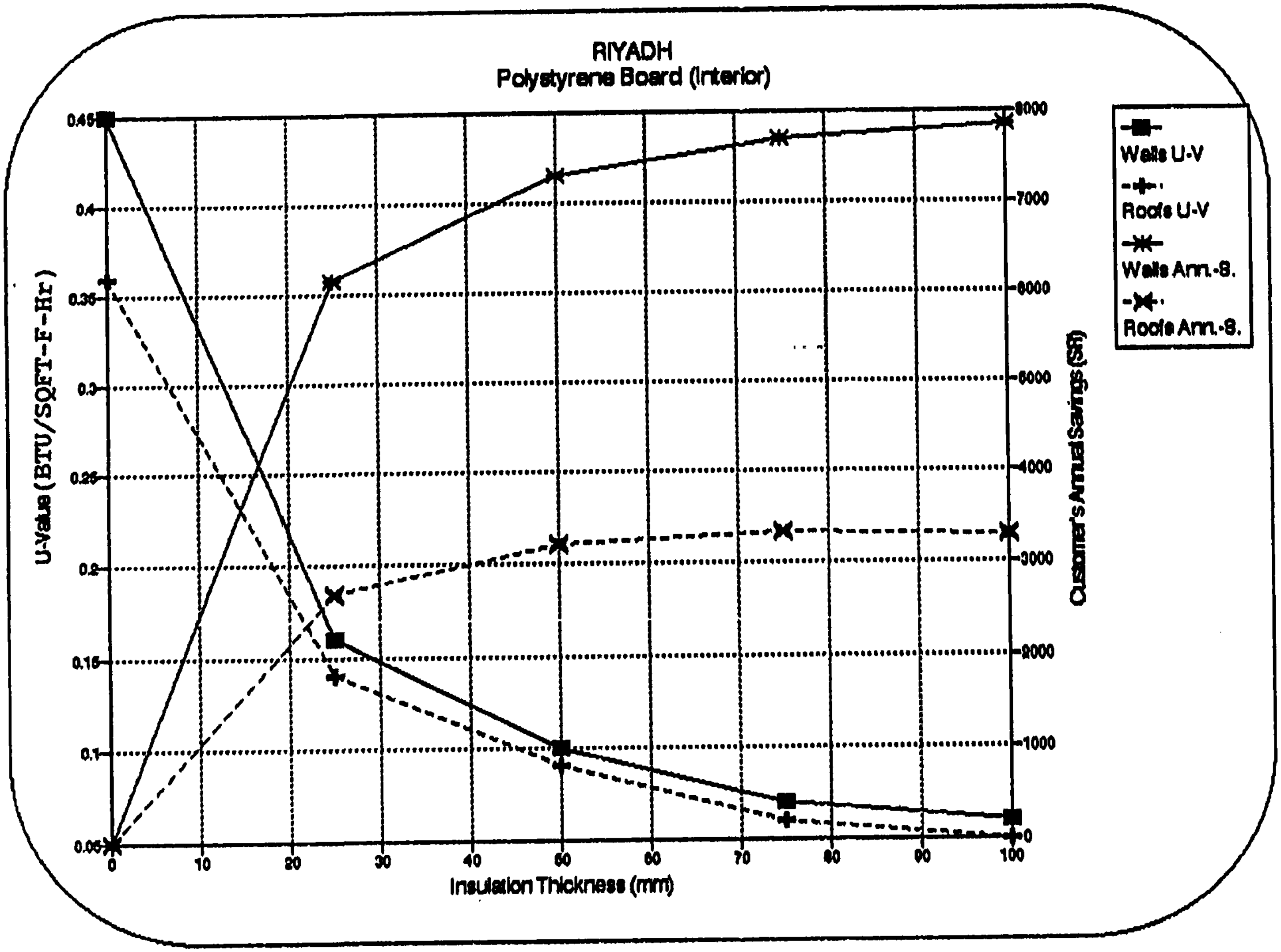


Figure 6.3: Riyadh - Polystyrene board (interior).

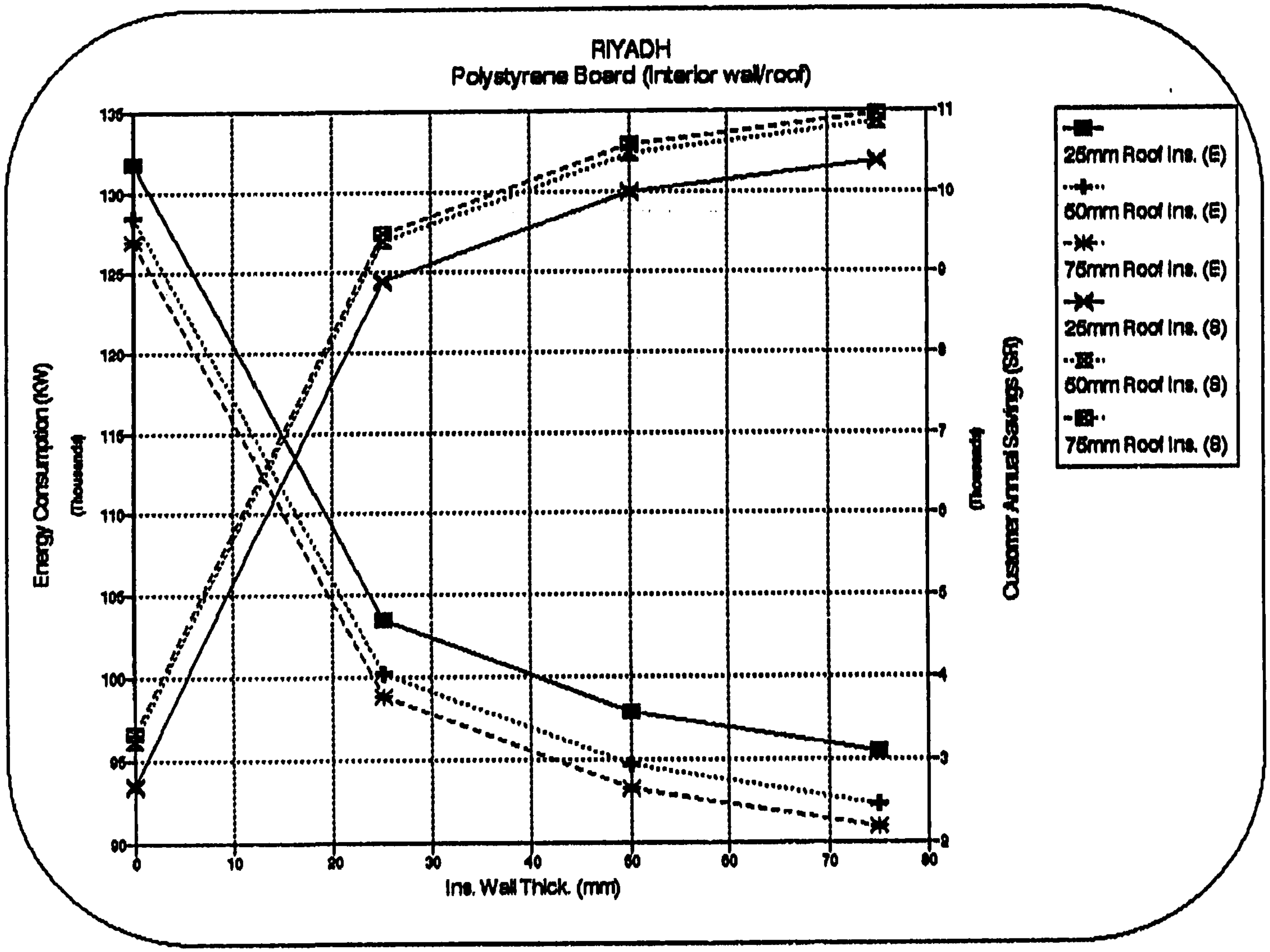


Figure 6.4: Riyadh - Polystyrene board (interior wall/roof).

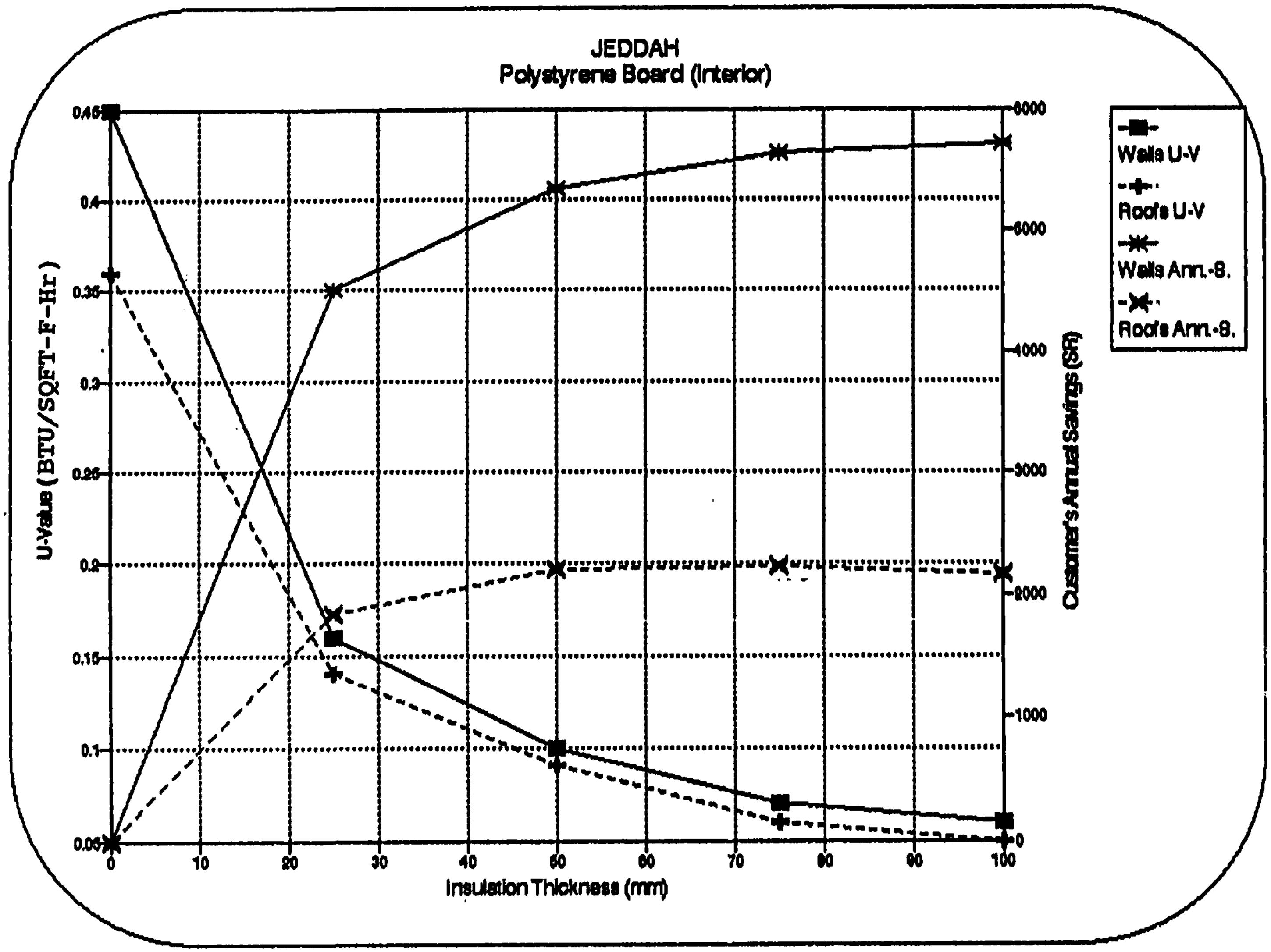


Figure 6.5: Jeddah - Polystyrene board (interior).

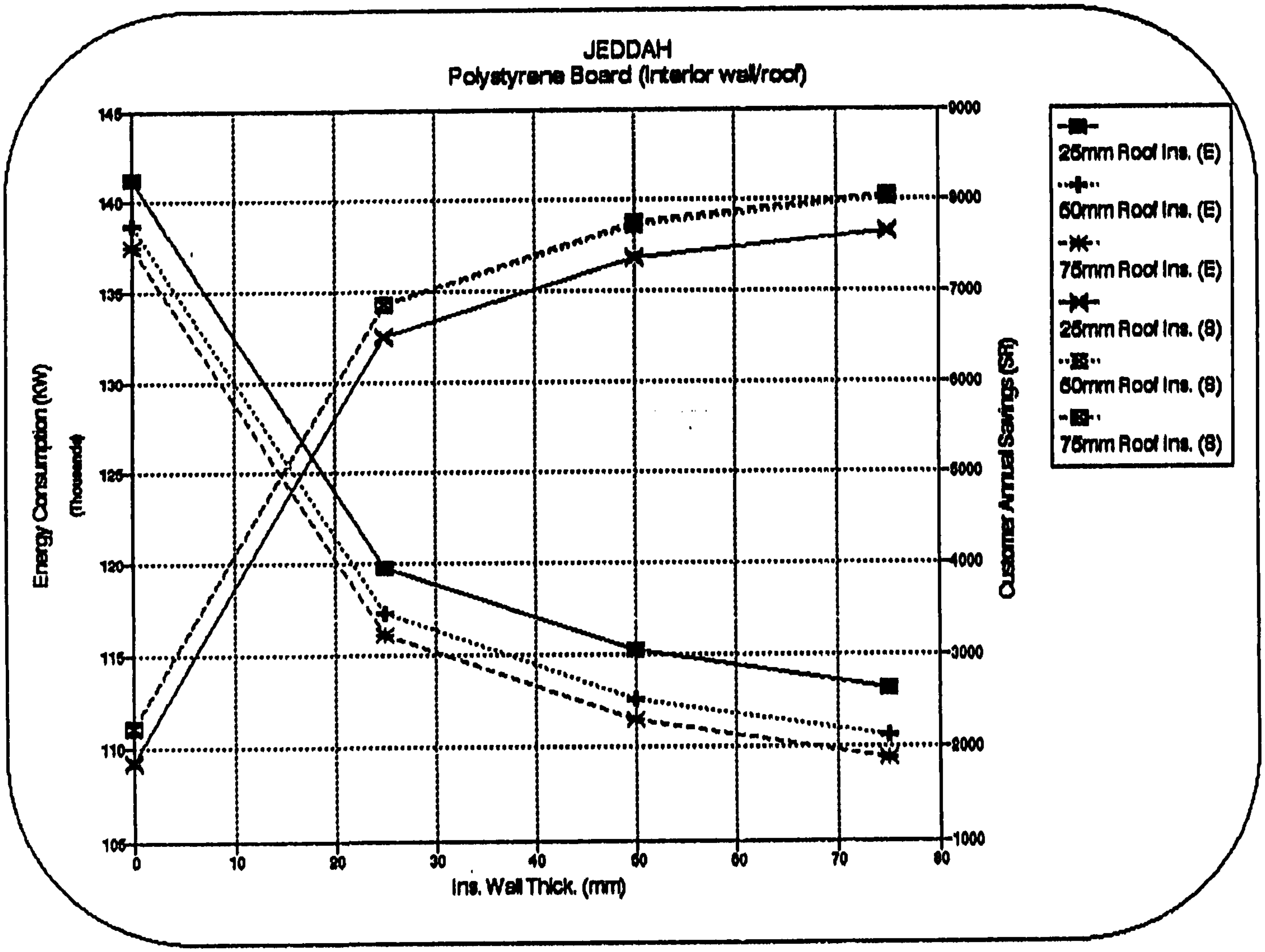


Figure 6.6: Jeddah - Polystyrene board (interior wall/ roof).

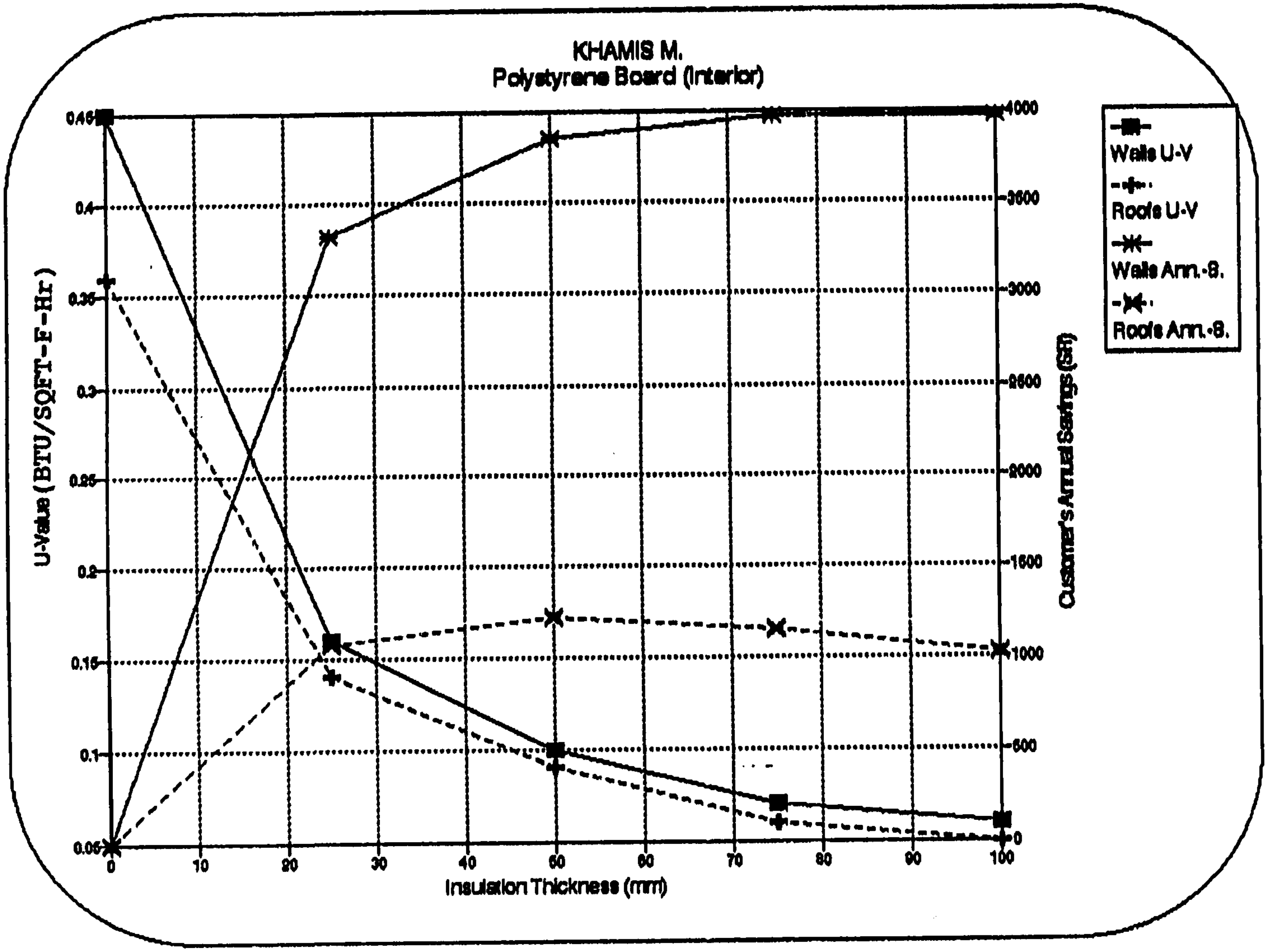


Figure 6.7: Khamis M. - Polystyrene board (interior).

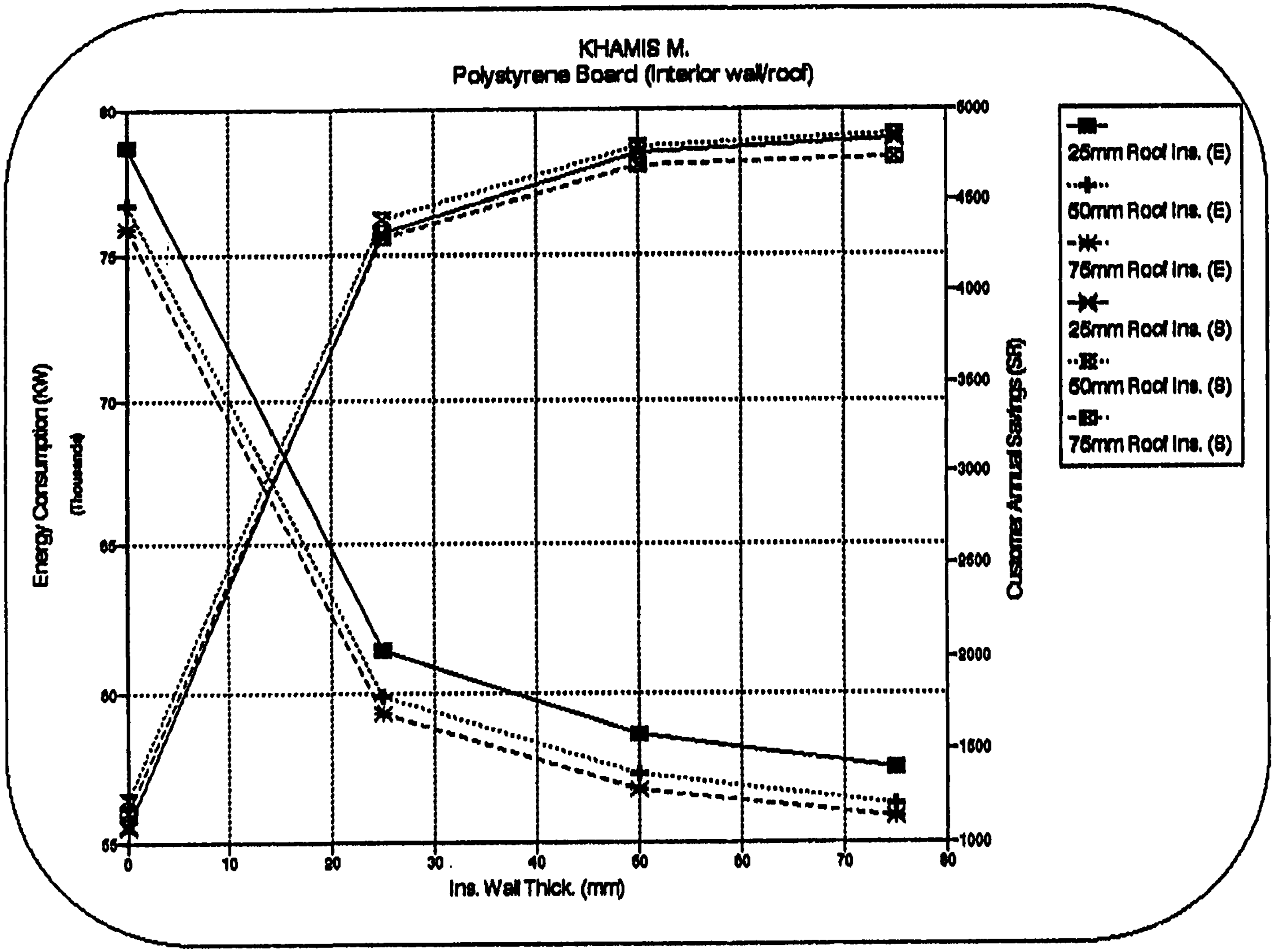


Figure 6.8: Khamis M. - Polystyrene board (interior wall/roof).

4. **Optimization graphs:** Due to the non-linearity and the complex equations to predict thermal loads and energy consumption, there was no simple optimization model to determine the optimum values. This led to the use of the graph approach which has been used by many researchers [25]. This is a direct approach utilizing the simulation results to predict the optimum savings for the insulation materials.. In this section, the economic performance of the different materials variations in each group for both walls and roofs will be presented. This type of figures will ease the comparison between the insulation materials within the groups and will show the economic performance of each material at different thicknesses.

5. **Wall and roof U-values (Customers):** In this section the thermal performance (U-values) of each wall and roof construction configuration is illustrated graphically versus the customer's annual savings. Each material and variation within a group is represented by a separate line. From these figures, the recommended U-values could be achieved.

6. **Wall and roof U-values (Government):** In this section the thermal performance of each wall and roof

construction configuration is illustrated graphically versus the government's annual savings. From these figures, the recommended U-values could be achieved and compared with the customer's U-values.

6.1.1 Dhahran city

6.1.1.1 Economic performance of walls

Table 6.2 lists the annual savings for the government and the customers for wall configurations in Dhahran city. To ease the comparison between different wall configurations, these results are illustrated graphically by a bar chart as shown in Figure 6.9.

Figure 6.9 shows that wall W6-3 (exterior 75mm polystyrene board) gives the best savings among group 1 for both government and customers.

In group 2, wall W10-1 (exterior 50mm fiberglass with reflective airspace) gives the best savings among the group for both the government and the customers.

In group 3, wall W12-1 (interior 50mm expanded polystyrene) gives the best savings for both government and customers.

In group 4, wall W13-2 (150mm fiberglass batt) gives the best saving among its group for both government and customers.

Finally, in group 5, wall W14-4 (cavity 75mm expanded polystyrene) gives the highest savings in its group for both government and customers.

Table 6.2: Dhahran - Annual savings (walls).

WALL	ROOF	GOVERN. ANNUAL SAVINGS	CUSTOM. ANNUAL SAVINGS
W 1-1	R 1-1	0.0	0.0
W 2-1	R 1-1	8801.3	5473.7
W 2-2	R 1-1	7461.4	4854.7
W 2-3	R 1-1	9882.2	5657.0
W 2-4	R 1-1	8590.5	3829.8
W 3-1	R 1-1	5887.9	3837.7
W 4-1	R 1-1	8954.4	5249.7
W 4-2	R 1-1	7670.6	4818.6
W 4-3	R 1-1	9502.7	5258.7
W 4-4	R 1-1	8716.2	3300.5
W 5-1	R 1-1	8912.0	5521.6
W 5-2	R 1-1	7638.3	4929.4
W 5-3	R 1-1	9461.2	5691.6
W 6-1	R 1-1	9496.5	5568.0
W 6-2	R 1-1	8485.2	5222.1
W 6-3	R 1-1	11741.8	6097.8
W 6-4	R 1-1	9421.6	5537.0
W 6-5	R 1-1	8552.2	5165.8
W 6-6	R 1-1	9855.2	5420.6
W 6-7	R 1-1	9058.7	3536.2
W 7-1	R 1-1	8899.8	5513.8
W 7-2	R 1-1	8762.6	5454.9
W 9-1	R 1-1	9099.0	5624.7
W 9-2	R 1-1	3557.5	2815.5
W 9-3	R 1-1	9055.4	5596.9
W 8-1	R 1-1	4481.4	2374.9
W 8-2	R 1-1	4460.6	2365.3
W 8-3	R 1-1	4477.4	2375.3
W10-1	R 1-1	6602.2	3299.1
W10-2	R 1-1	0.0	0.0
W10-3	R 1-1	4589.7	2443.1
W10-4	R 1-1	4604.7	2764.4
W11-1	R 1-1	6404.3	2862.6
W11-2	R 1-1	1553.8	934.9
W11-3	R 1-1	6401.7	2860.8
W12-1	R 1-1	8740.5	5439.4
W12-2	R 1-1	0.0	0.0
W13-1	R 1-1	6531.1	3462.8
W13-2	R 1-1	7001.3	3664.1
W13-3	R 1-1	0.0	0.0
W14-1	R 1-1	4155.0	2161.4
W14-2	R 1-1	0.0	0.0
W14-3	R 1-1	3019.6	1643.7
W14-4	R 1-1	4661.2	2309.5

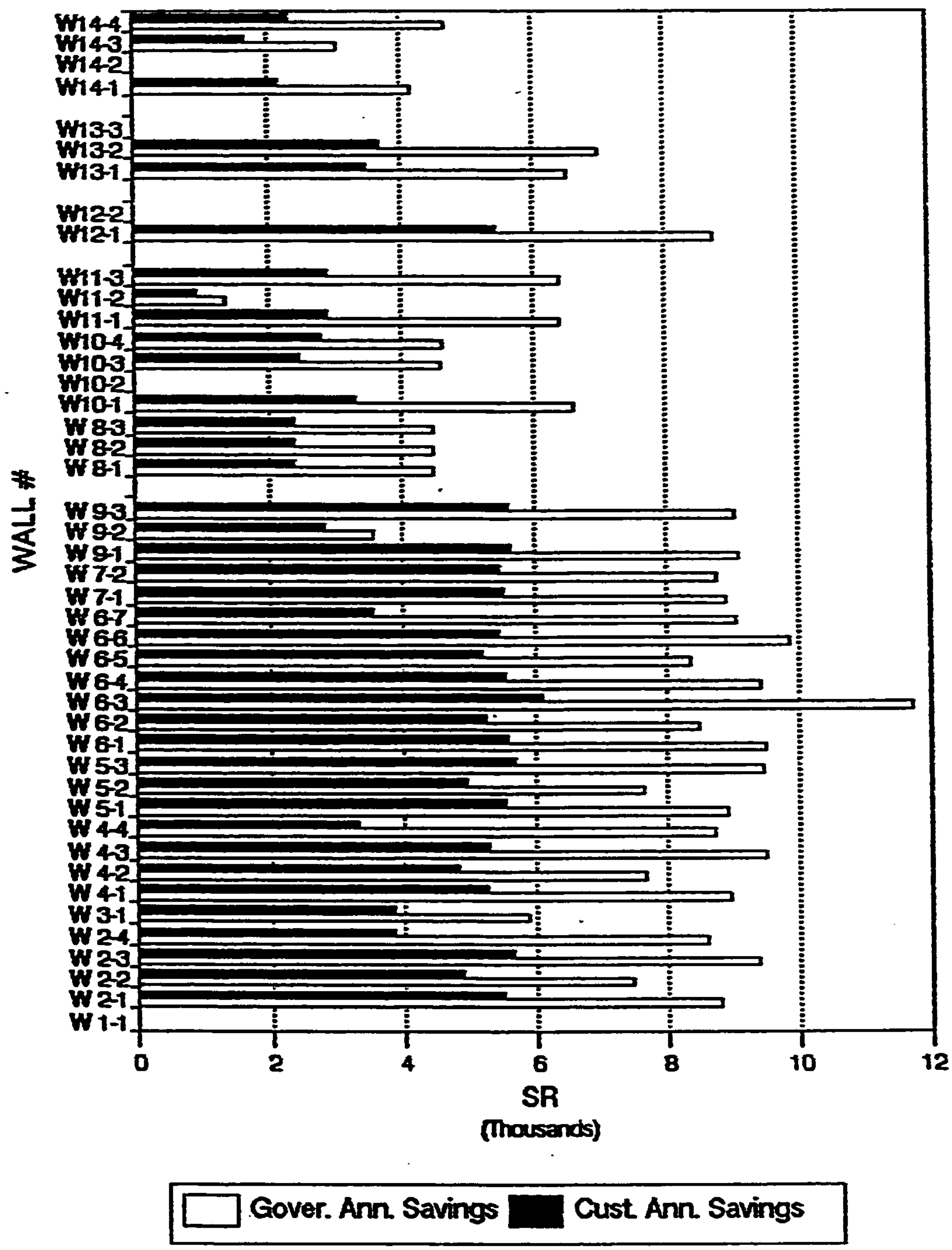


Figure 6.9: Dhahran - Annual savings (walls).

6.1.1.2 Economic performance of roofs

Table 6.3 shows the economical performance of roofs in Dhahran city. This is illustrated graphically in Figure 6.10.

This figure shows that for group 1, roof R2-5 (exterior 75mm expanded polystyrene) gives the maximum customer's annual savings, while roofs R2-4 (exterior 100mm extruded polystyrene) and R3-1 (exterior 75mm polyurethane) give the maximum government's annual savings.

In group 2, roof R7-3 (exterior 50mm expanded polystyrene) gives the highest savings in this group for both government and customers.

In group 3, roof R8-3 (interior 150mm fiberglass batt) gives the best government and customer's annual saving.

In group 4, roof R9-1 (exterior 75mm extruded polystyrene) gives the maximum annual savings for the customers, while roof R9-2 (exterior 100mm extruded polystyrene) gives the highest annual savings for the government.

In group 5, roof R10-3 (exterior 50mm extruded polystyrene) gives the highest annual savings for the customers, while roof R10-1 (exterior 75mm extruded polystyrene) gives the highest annual savings for the government.

In the last group, roof R11-1 (exterior 75mm extruded polystyrene) gives the highest annual savings for both the customers and the government.

Table 6.3: Dhahran - Annual savings (roofs).

WALL	ROOF	GOVERN. ANNUAL SAVINGS	CUSTOM. ANNUAL SAVINGS
W 1-1	R 1-1	0.0	0.0
W 1-1	R 2-1	4201.4	2644.0
W 1-1	R 2-2	2475.9	1278.3
W 1-1	R 2-3	3197.1	1519.9
W 1-1	R 2-4	4380.2	2535.5
W 1-1	R 2-5	4097.9	2713.0
W 1-1	R 2-6	2314.4	1221.8
W 1-1	R 2-7	3070.5	1531.4
W 1-1	R 2-8	2206.5	-817.8
W 1-1	R 3-1	4587.8	2029.7
W 1-1	R 4-1	3517.5	1504.4
W 1-1	R 4-2	3505.9	1496.1
W 1-1	R 4-3	3480.1	1481.5
W 1-1	R 5-1	5506.2	1313.6
W 1-1	R 5-2	2458.5	1084.1
W 1-1	R 5-3	3185.0	1328.3
W 1-1	R 5-4	3693.1	1212.3
W 1-1	R 6-1	0.0	0.0
W 1-1	R 7-1	3222.7	1442.3
W 1-1	R 7-2	2603.1	1858.1
W 1-1	R 7-3	3451.8	2513.9
W 1-1	R 7-4	2009.2	-955.5
W 1-1	R 8-1	1965.0	-280.8
W 1-1	R 8-2	1763.9	-18.7
W 1-1	R 8-3	2880.6	221.7
W 1-1	R 8-4	0.0	0.0
W 1-1	R 9-1	4375.8	1628.5
W 1-1	R 9-2	4627.1	1446.4
W 1-1	R 9-3	0.0	0.0
W 1-1	R10-1	6626.9	2853.9
W 1-1	R10-2	0.0	0.0
W 1-1	R10-3	6252.8	2929.5
W 1-1	R11-1	2188.4	1151.3
W 1-1	R11-2	0.0	0.0
W 1-1	R11-3	1303.9	191.4

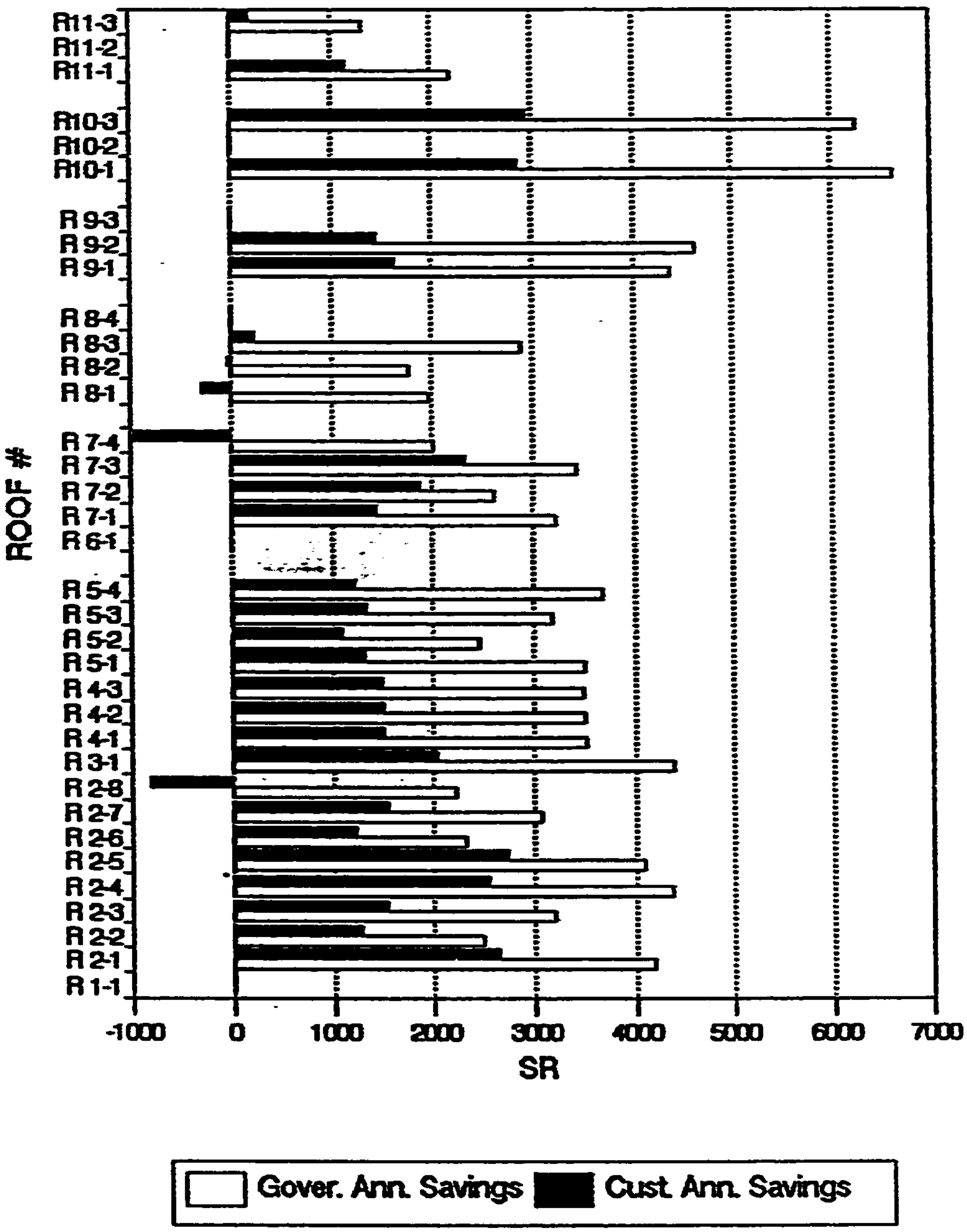


Figure 6.10: Dhahran - Annual savings (roofs).

6.1.1.3 Combined performance

Figure 6.11 shows the government and customer's annual savings when insulating both walls and roofs simultaneously (combination) in Dhahran city. From this bar chart, it is clear that the combinations of W2-3 R2-3 (interior 75mm expanded polystyrene on a CMU wall and exterior 50mm extruded polystyrene on a reinforced concrete roof) and W5-3 R2-3 (exterior 75mm expanded polystyrene on a CMU wall and exterior 50mm extruded polystyrene on a reinforced concrete roof) give the highest annual savings for the customer. For the government, the combinations of W2-3 R2-4 (interior 75mm expanded polystyrene on a CMU wall and exterior 100mm extruded polystyrene on a reinforced concrete roof) and W5-3 R2-4 (exterior 75mm expanded polystyrene on a CMU wall and exterior 100mm extruded polystyrene on a reinforced concrete roof) give the maximum government's annual savings.

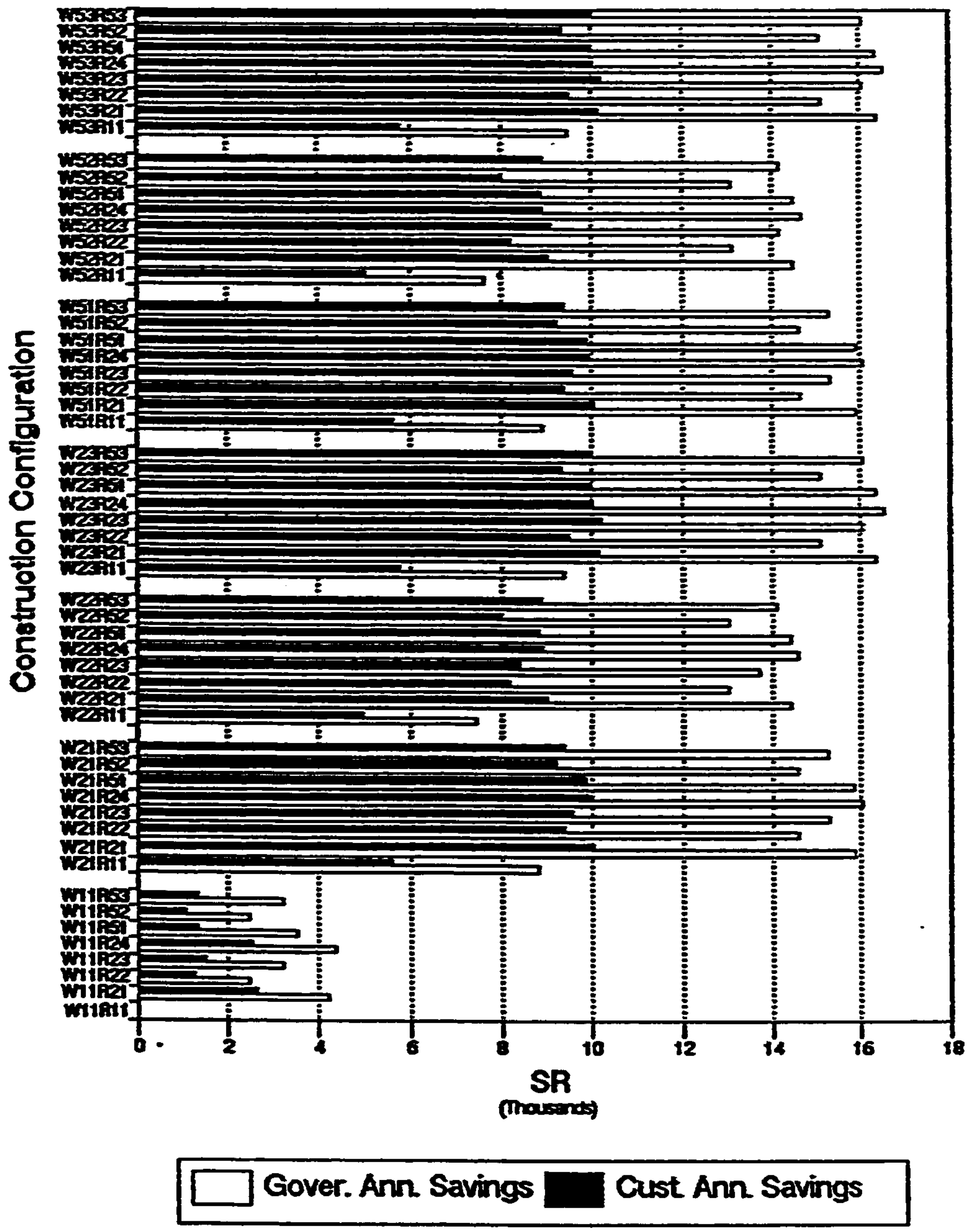


Figure 6.11: Dhahran - Annual savings (combinations).

6.1.1.4 Optimization graphs

As was mentioned earlier, the graph approach will be used to determine the best economic performance for different insulation materials both in walls and roofs.

In order to compare the economic performance of each material within its group, Figures 6.12 through 6.15 illustrate the economic performance of each material among its group for both walls and roofs. From these figures, the following can be seen:

- Figure 6.12 shows that the polyurethane board when used on the exterior of the CMU wall will give the best economic performance.
- Figure 6.13 shows that among the rest of the walls groups (groups 2 to 5) in Dhahran city, the interior expanded polystyrene on the split-faced block wall will show the best economic performance.
- Figure 6.14 shows that among group 1 of the roofs in Dhahran, the expanded polystyrene when used on the exterior of a reinforced concrete roof will give the highest customer's annual savings only at a thickness of 75mm. But as a whole performance, the extruded polystyrene when used on the exterior of the reinforced concrete roof will give the best economic performance.

- Figure 6.15 shows that the extruded polystyrene when used on the exterior of a precast hollow core roof will show the best economic performance among the roof groups 2 to 6.

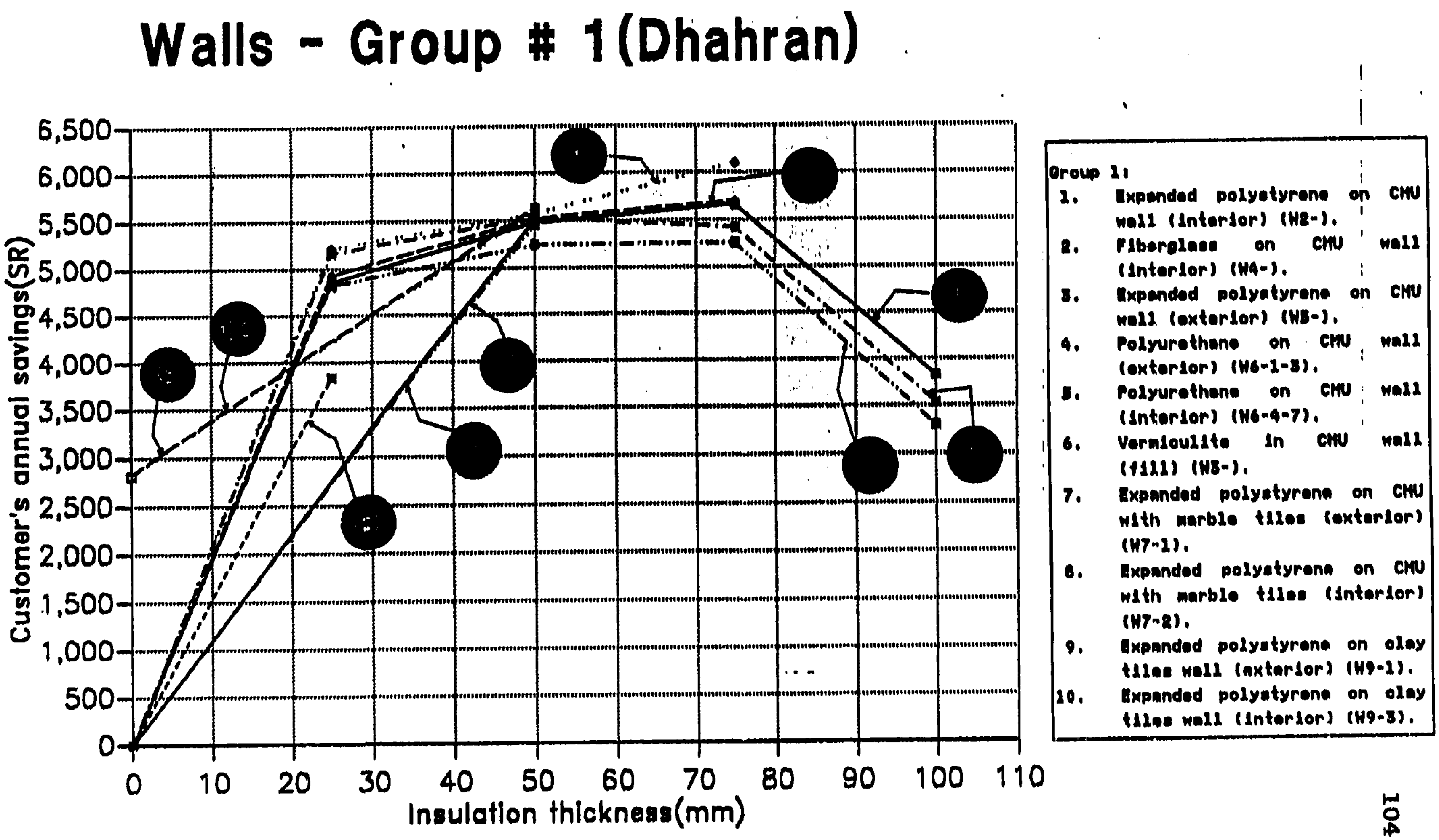
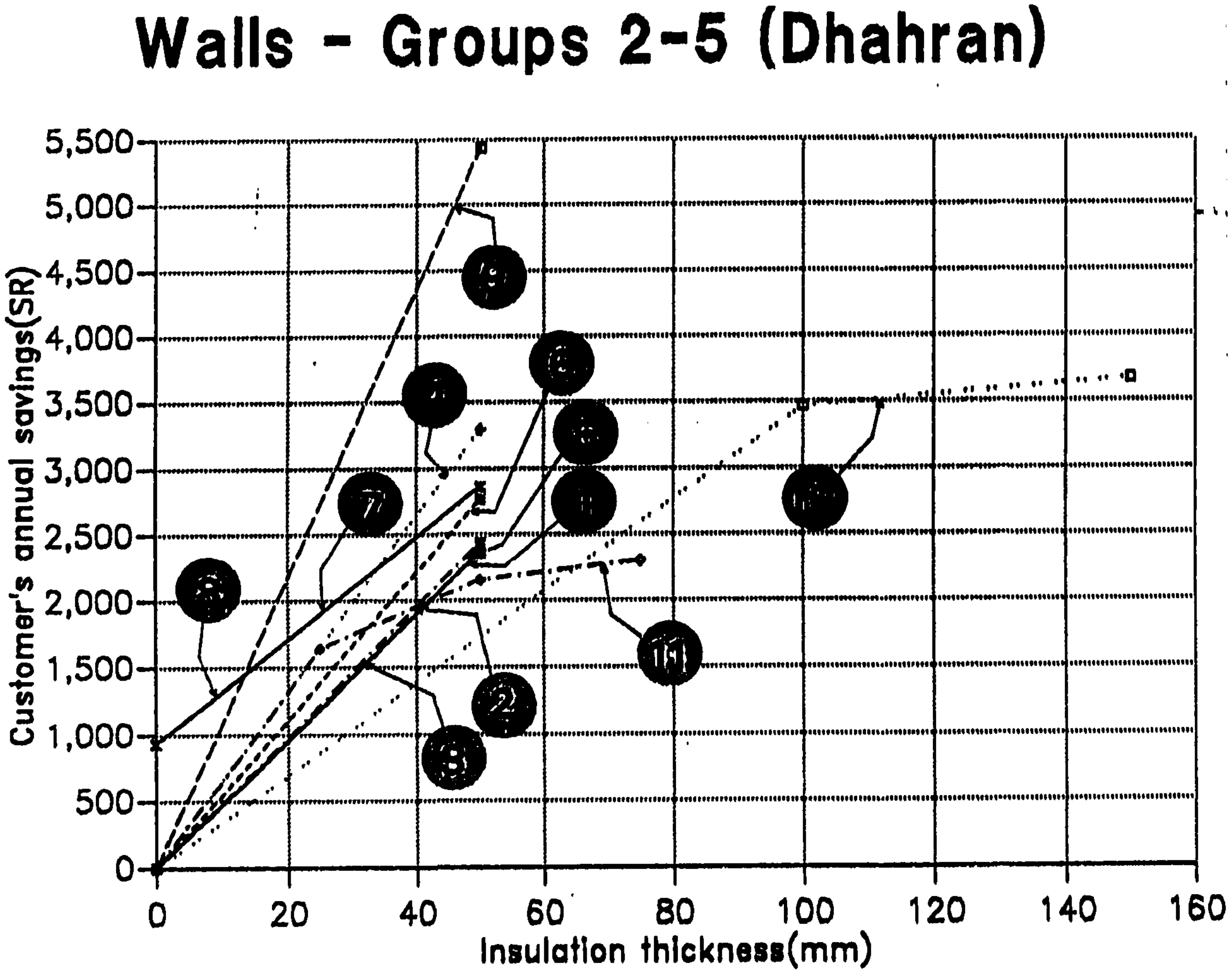


Figure 6.12: Dhahran - Walls # 1 (Economic performance).



Group 2:
1. Expanded polystyrene in CMU and brick wall (exterior) (W8-1).
2. Expanded polystyrene in CMU and brick wall (interior) (W8-2).
3. Expanded polystyrene with airspace in CMU and brick wall (interior) (W8-3).
4. Fiberglass with reflective airspace in CMU and brick wall (exterior) (W10-1).
5. Fiberglass in CMU and brick wall (interior) (W10-3).
6. Fiberglass with no reflective airspace in CMU and brick wall (exterior) (W10-4).
7. Expanded polystyrene in clay tiles and brick wall (exterior) (W11-1).
8. Expanded polystyrene in clay tiles and brick wall (interior) (W11-3).

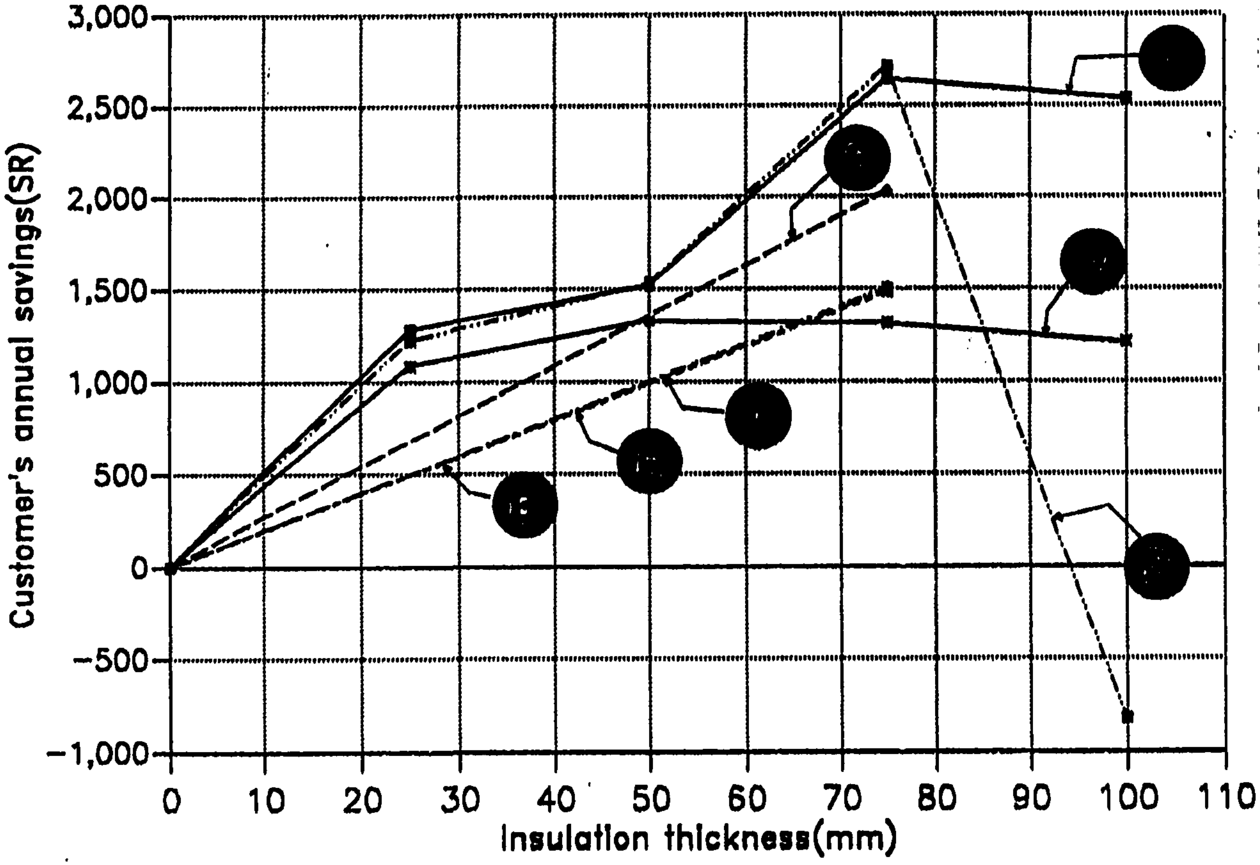
Group 3:
9. Expanded polystyrene on split faced block (interior) (W12-).

Group 4:
10. Fiberglass batt in metal studs (W13-).

Group 5:
11. Expanded polystyrene in cavity of two solid CMU walls (W14-).

Figure 6.13: Dhahran - Walls # 2 - 5 (Economic performance).

Roofs - Group # 1(Dhahran)



Group 1:

1. Extruded polystyrene on reinforced concrete roof (exterior) (R2-1-4).
2. Expanded polystyrene on reinforced concrete roof (exterior) (R2-5-6).
3. Polyurethane on reinforced concrete roof (exterior) (R3-1).
4. Extruded polystyrene on inverted reinforced concrete roof (exterior) (R4-1).
5. Extruded polystyrene on inverted reinforced concrete roof without mortar (exterior) (R4-2).
6. Extruded polystyrene on inverted reinforced concrete roof without mortar and sand (exterior) (R4-3).
7. Extruded polystyrene on reinforced concrete roof (interior) (R5-).

Figure 6.14: Dhahran - Roofs # 1 (Economic performance).

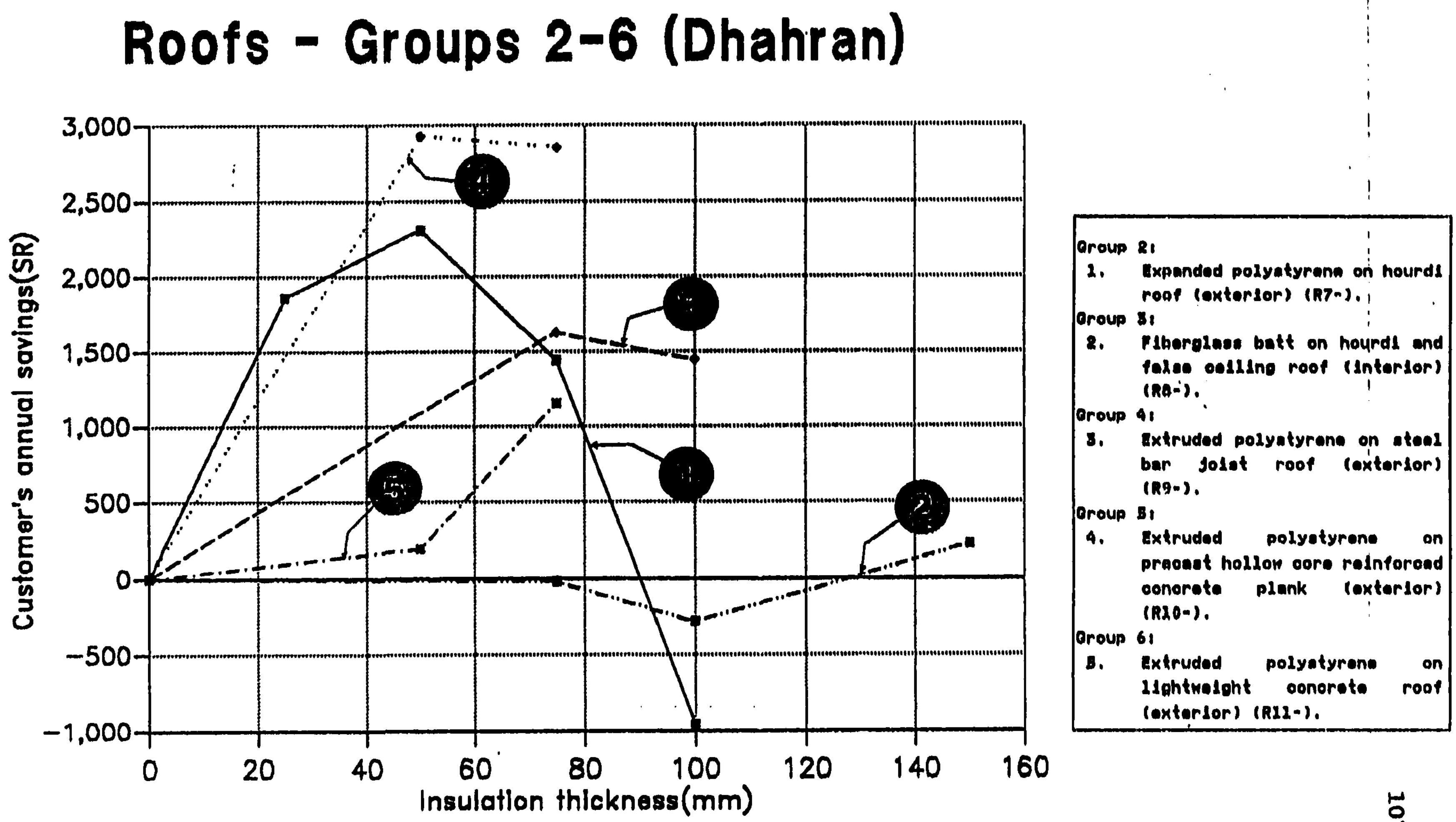


Figure 6.15: Dhahran - Roofs # 2 - 6 (Economic performance).

6.1.1.5 Wall and roof U-values (Customers)

In this section, the thermal performance of the insulation materials is represented graphically versus the customer's annual savings, from which recommended U-values could be achieved. The thermal performance of each variation within a group of walls or roofs is represented by a line, so that a maximum U-value and a range of recommended U-values (within 10%) could be achieved for each group. This is shown in Figures 6.16 through 6.19. The extracted U-values from these figures are summarized in section 6.2.

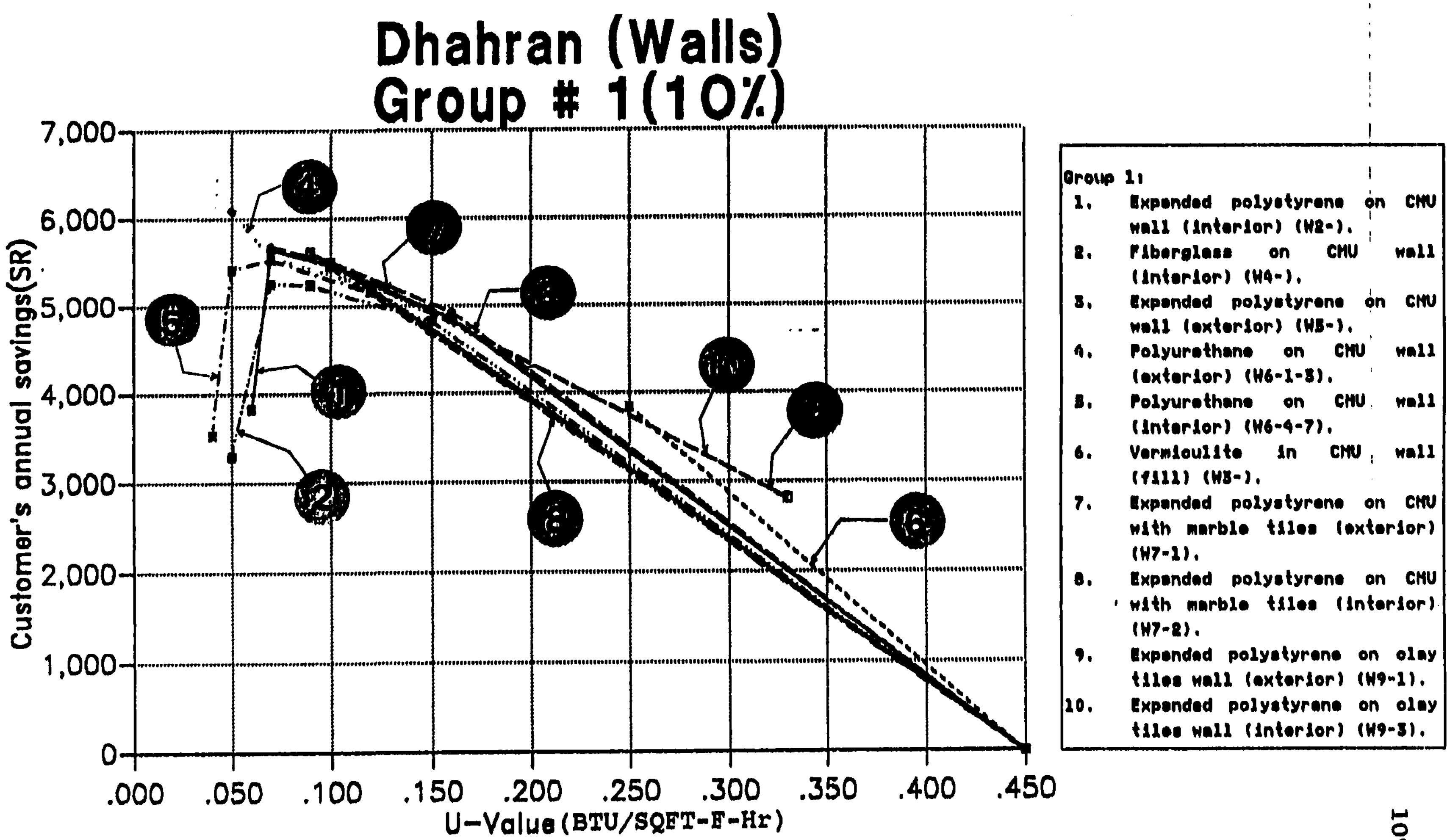


Figure 6.16: Dhahran - Walls # 1 (Thermal performance (customer)).

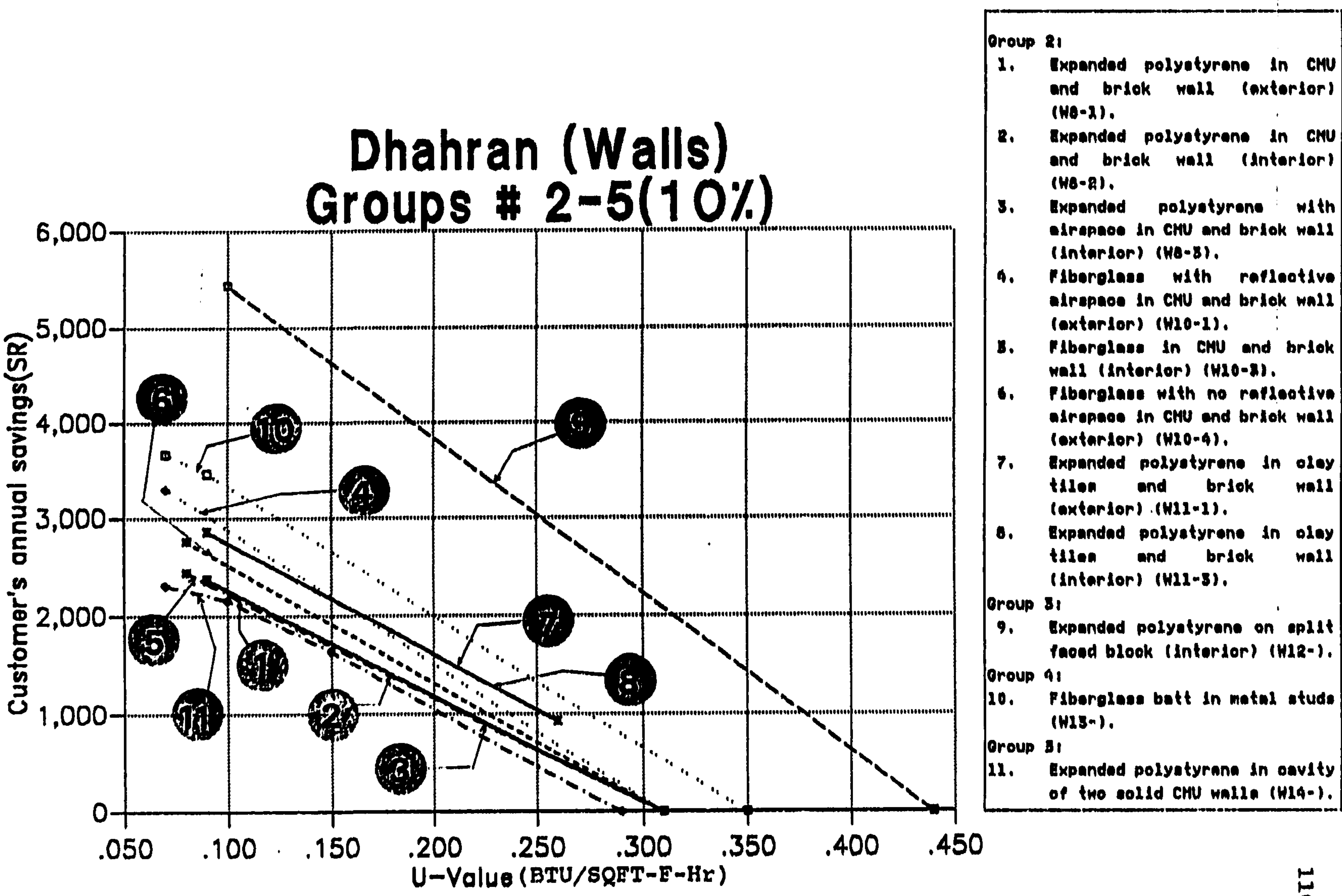


Figure 6.17: Dhahran - Walls # 2 -5 (Thermal performance (customer)).

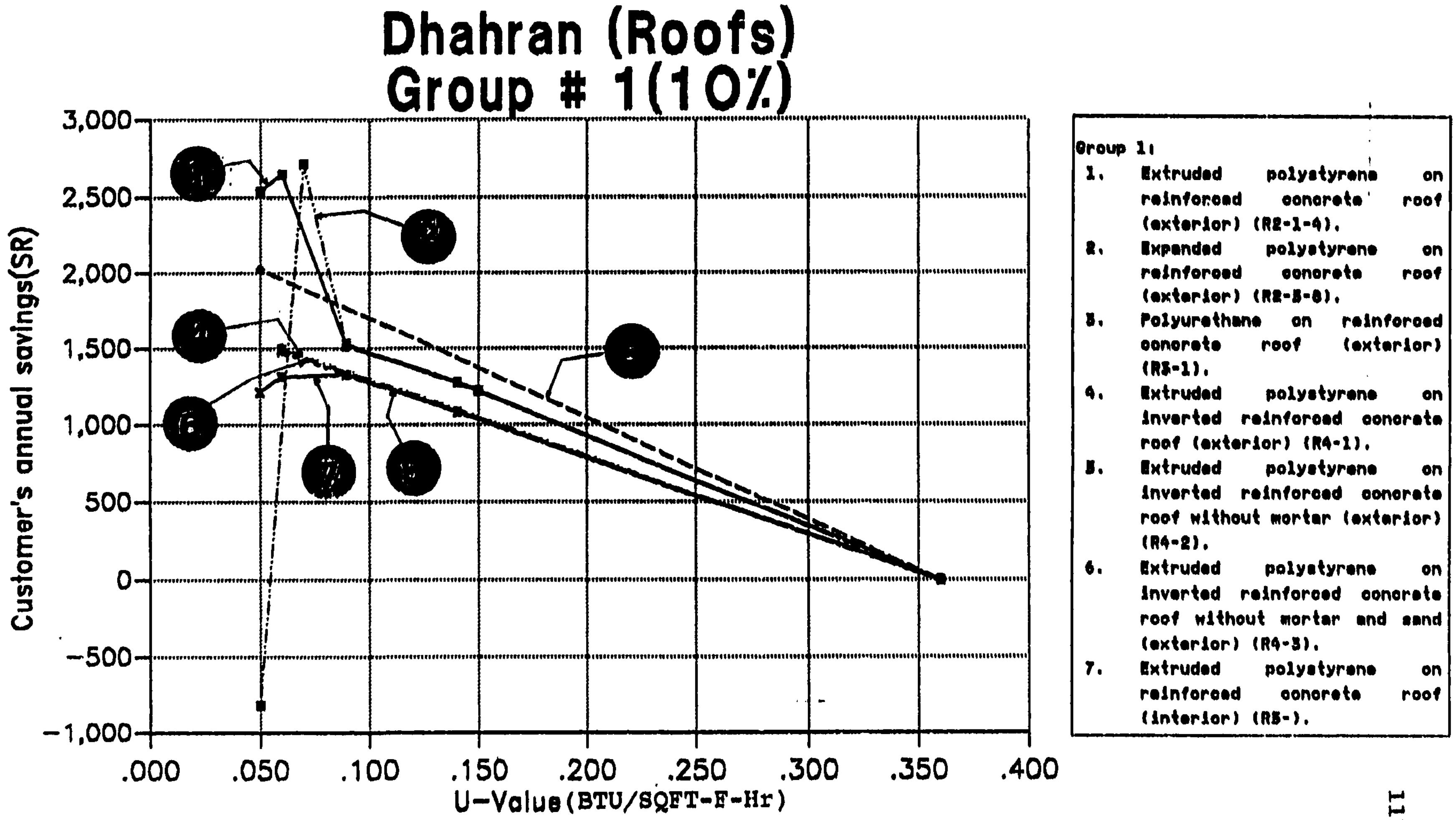
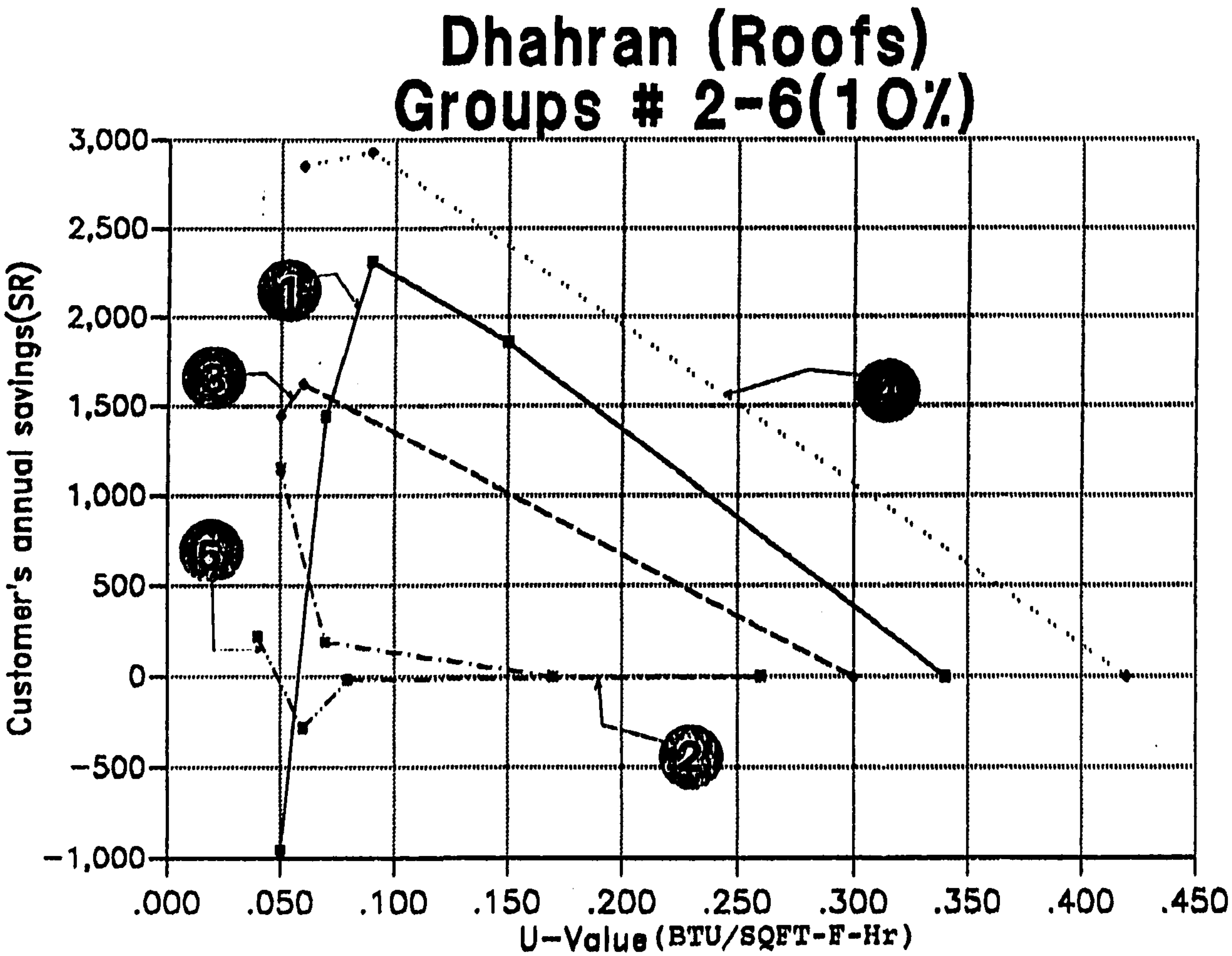


Figure 6.18: Dhahran - Roofs # 1 (Thermal performance (customer)).



Group 2:
1. Expanded polystyrene on hourdi roof (exterior) (R7-).
Group 3:
2. Fiberglass batt on hourdi and false ceiling roof (interior) (R8-).
Group 4:
3. Extruded polystyrene on steel bar joist roof (exterior) (R9-).
Group 5:
4. Extruded polystyrene on precast hollow core reinforced concrete plank (exterior) (R10-).
Group 6:
5. Extruded polystyrene on lightweight concrete roof (exterior) (R11-).

Figure 6.19: Dhahran - Roofs # 2 - 6 (Thermal performance (customer)).

6.1.1.6 Wall and roof U-values (Government)

In this section, the thermal performance of the insulation materials is represented graphically versus the government's annual savings. From these figures a maximum U-value and a range of recommended U-values for each group could be achieved for each group and compared with the customer's U-values. This is shown in Figures 6.20 through 6.23. The extracted U-values from these figures are summarized in section 6.2.

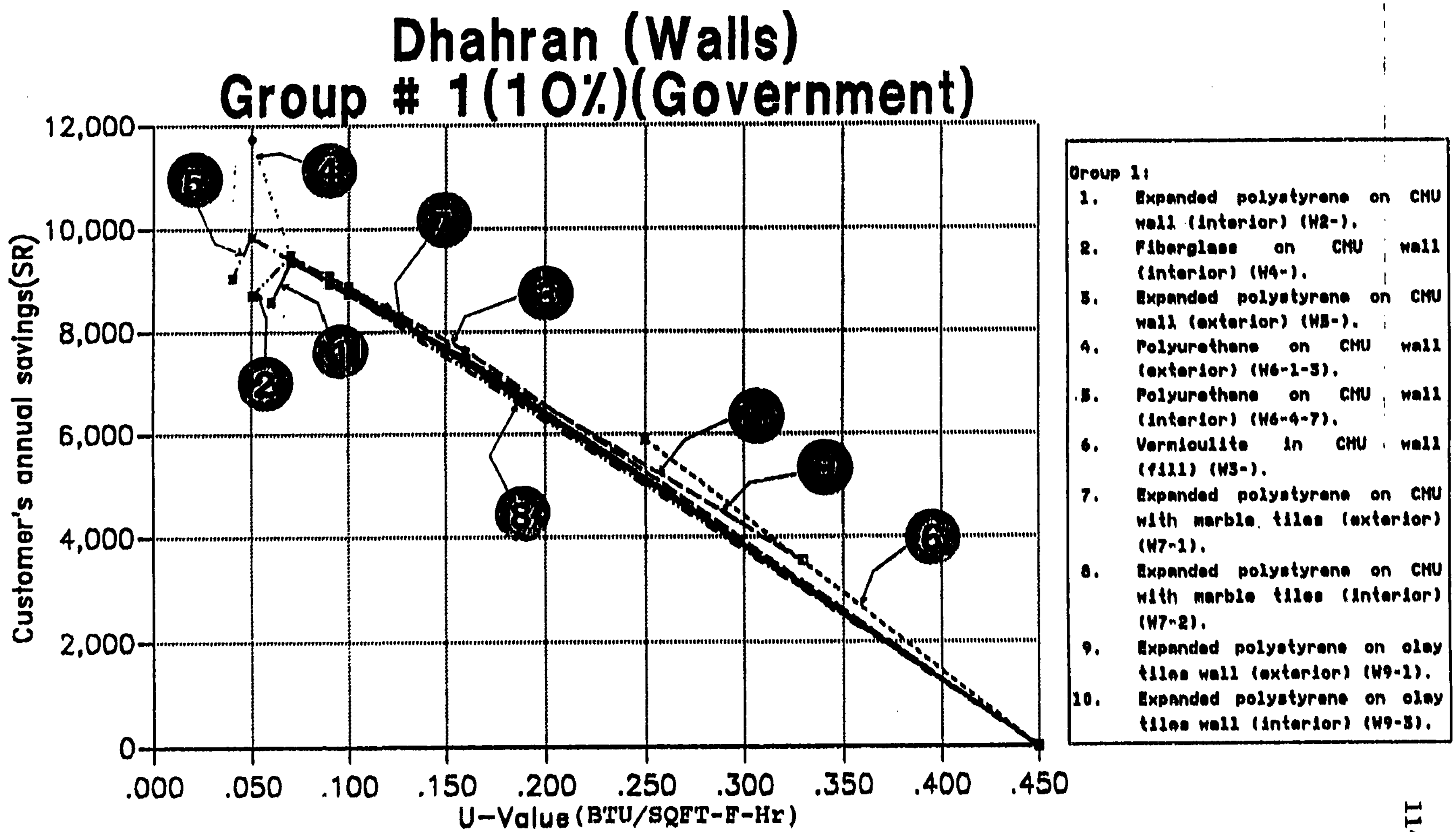
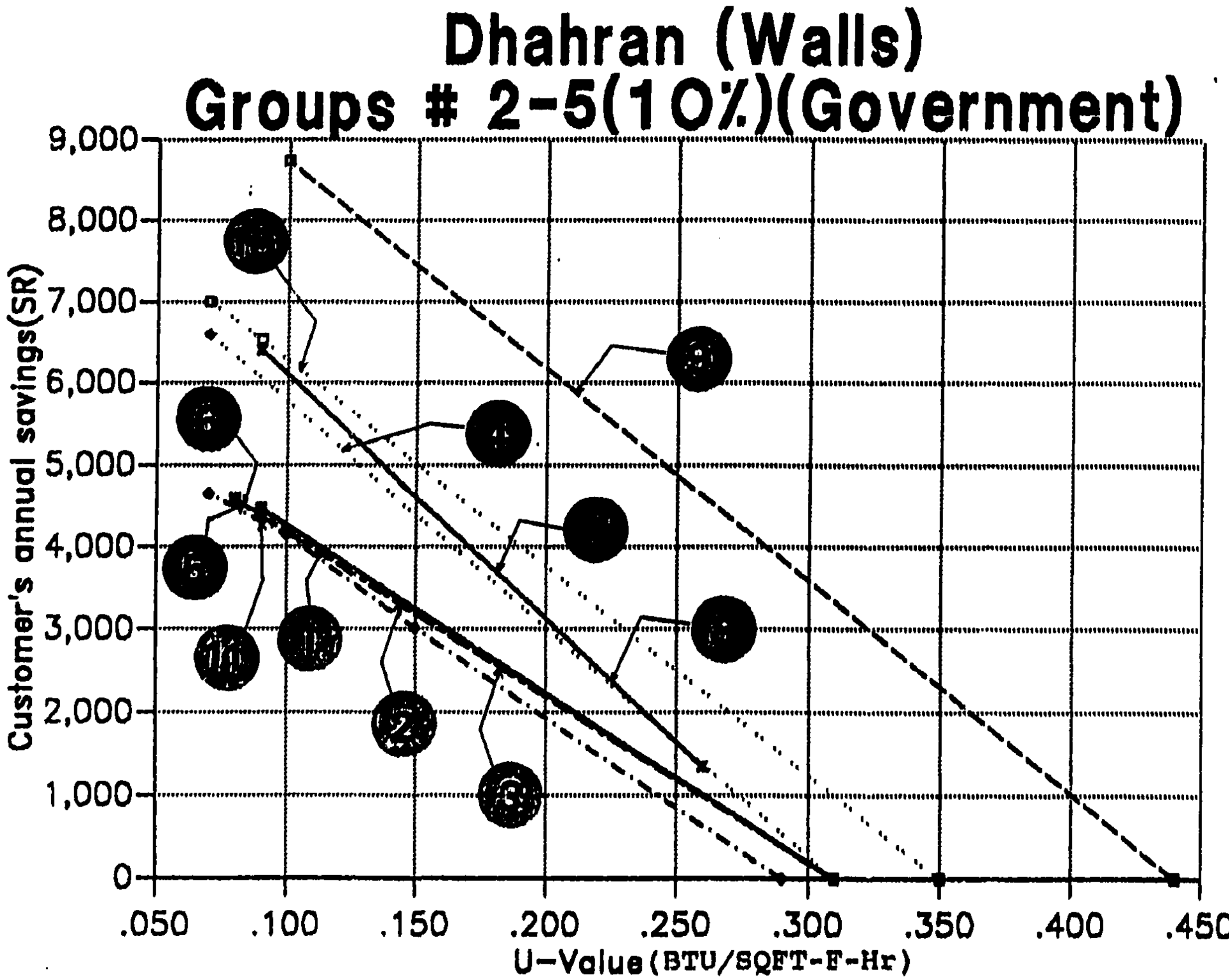


Figure 6.20: Dhahran - Walls # 1 (Thermal performance (government)).



Group 2:
1. Expanded polystyrene in CMU and brick wall (exterior) (W8-1).
2. Expanded polystyrene in CMU and brick wall (interior) (W8-2).
3. Expanded polystyrene with airspace in CMU and brick wall (interior) (W8-3).
4. Fiberglass with reflective airspace in CMU and brick wall (exterior) (W10-1).
5. Fiberglass in CMU and brick wall (interior) (W10-3).
6. Fiberglass with no reflective airspace in CMU and brick wall (exterior) (W10-4).
7. Expanded polystyrene in clay tiles and brick wall (exterior) (W11-1).
8. Expanded polystyrene in clay tiles and brick wall (interior) (W11-3).

Group 3:
9. Expanded polystyrene on split faced block (interior) (W12-).

Group 4:
10. Fiberglass batt in metal studs (W13-).

Group 5:
11. Expanded polystyrene in cavity of two solid CMU walls (W14-).

Figure 6.21: Dhahran - Walls # 2 -5 (Thermal performance (government)).

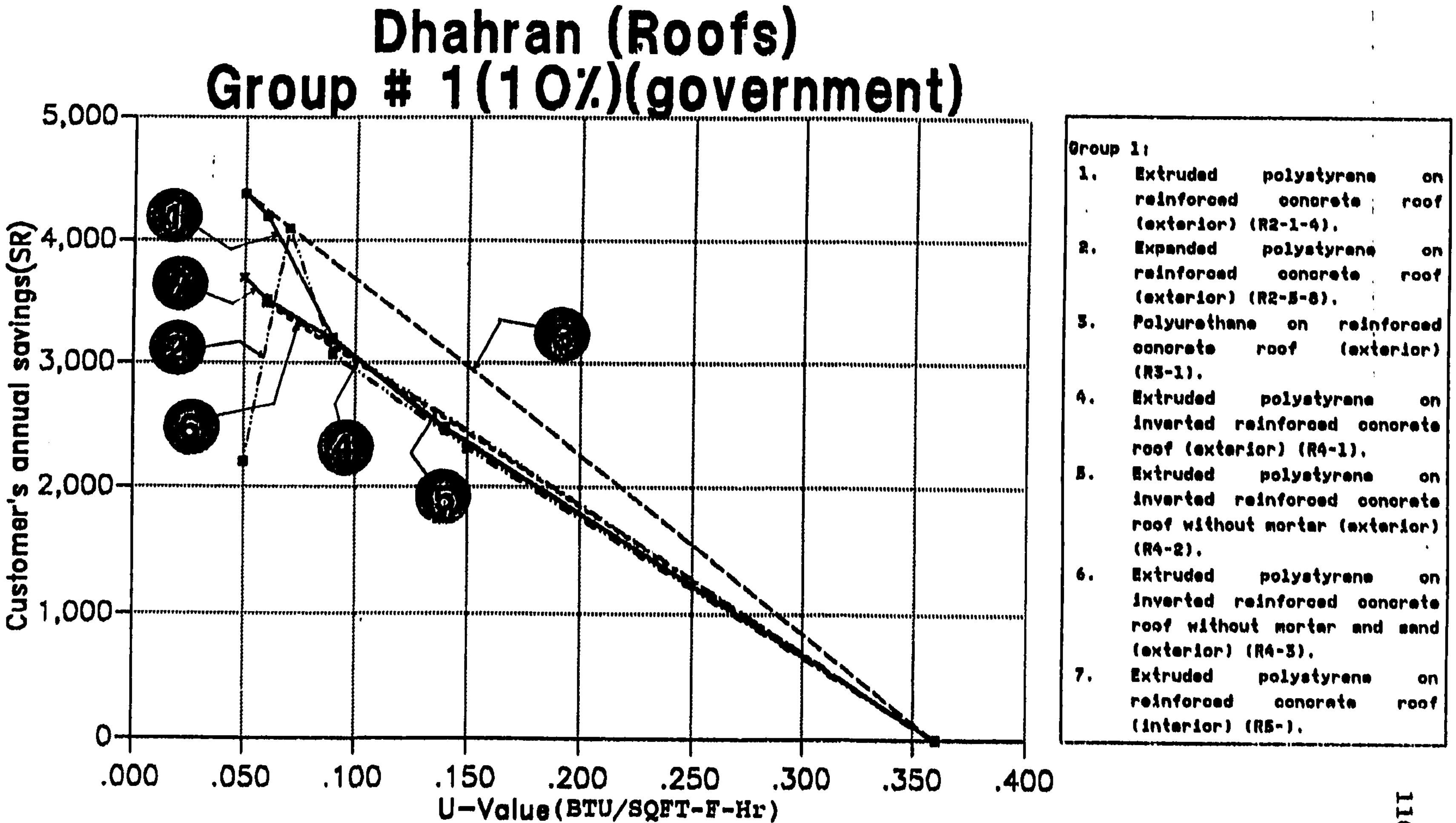
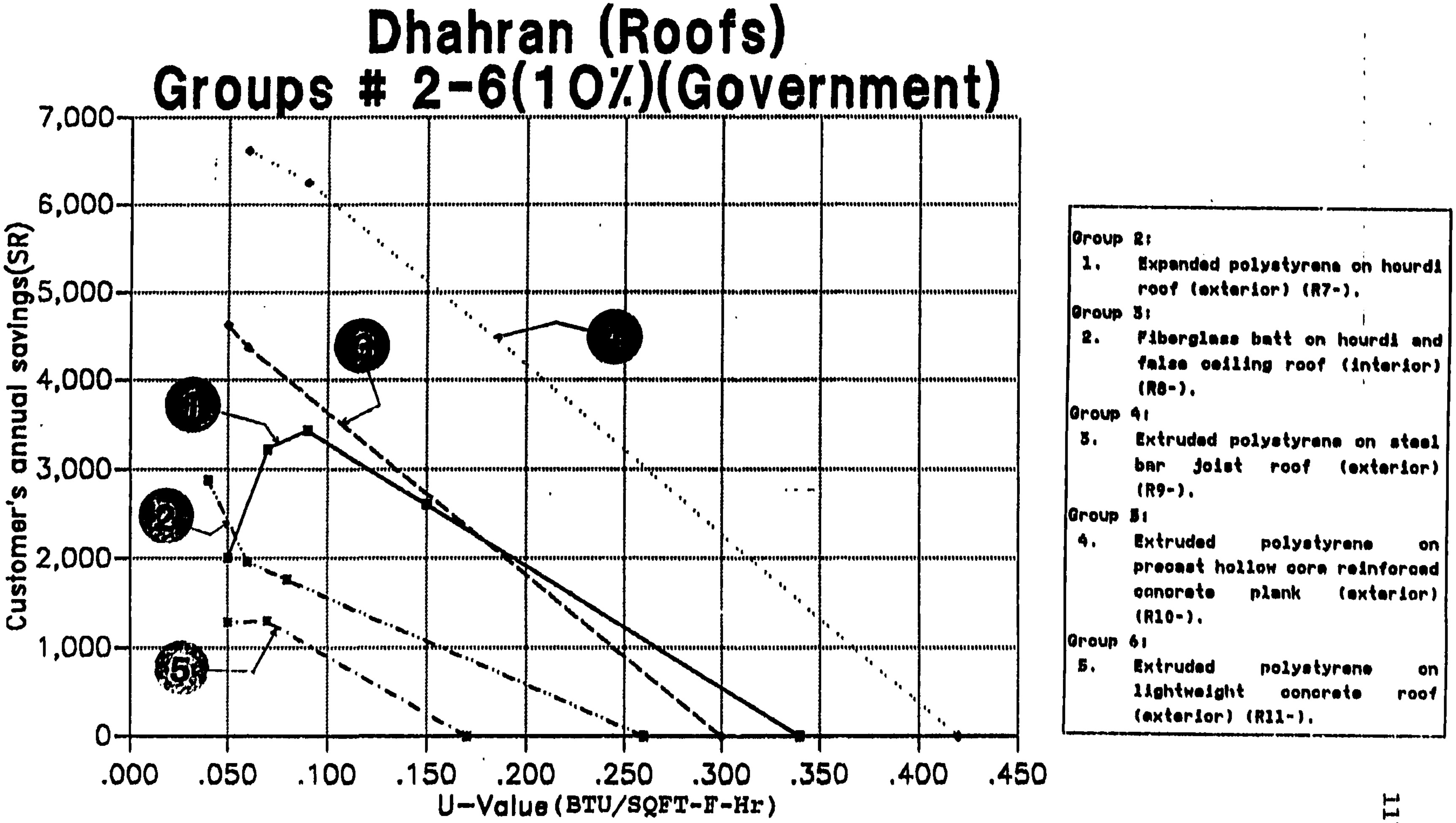


Figure 6.22: Dhahran - Roofs # 1 (Thermal performance (government)).



<u>Figure 6.23</u>: Dhahran - Roofs # 2 - 6 (Thermal performance (government)).

6.1.2 Riyadh city

6.1.2.1 Economic performance of walls

Table 6.4 lists the annual savings for the government and the customers for wall configurations in Riyadh city. These results are illustrated graphically by a bar chart as shown in Figure 6.24.

Figure 6.24 shows that wall W2-4 (interior 100mm expanded polystyrene board) gives the best savings among group 1 for the customers. Wall W6-7 (interior 100mm polyurethane board) gives the best government's annual savings.

In group 2, wall W10-4 (exterior 50mm fiberglass with a non reflective airspace) gives the best savings among the group for the customers. For the government, wall W10-1 (exterior 50mm fiberglass with reflective airspace) gives the highest government's annual savings.

In group 3, wall W12-1 (interior 50mm expanded polystyrene) gives the best savings for both government and customers.

In group 4, wall W13-2 (150mm fiberglass batt) gives the best saving among its group for both government and customers.

Finally, in group 5, wall W14-4 (cavity 75mm expanded polystyrene) gives the highest savings in its group for both government and customers.

Table 6.4: Riyadh - Annual savings (walls).

WALL	ROOF	GOVERN. ANNUAL SAVINGS	CUSTOM. ANNUAL SAVINGS
W 1-1	R 1-1	6.0	0.0
W 2-1	R 1-1	10298.7	7308.5
W 2-2	R 1-1	8592.4	6164.3
W 2-3	R 1-1	11033.0	7710.5
W 2-4	R 1-1	11443.5	7865.7
W 3-1	R 1-1	6680.4	4557.3
W 4-1	R 1-1	10496.5	7150.0
W 4-2	R 1-1	8860.8	6211.8
W 4-3	R 1-1	11196.5	7372.4
W 4-4	R 1-1	11582.9	7347.8
W 5-1	R 1-1	10427.3	7389.6
W 5-2	R 1-1	8809.4	6304.1
W 5-3	R 1-1	11128.3	7776.6
W 6-1	R 1-1	11169.6	7659.4
W 6-2	R 1-1	9888.0	6926.6
W 6-3	R 1-1	11685.6	7683.3
W 6-4	R 1-1	11089.1	7613.5
W 6-5	R 1-1	9730.1	6828.3
W 6-6	R 1-1	11651.9	7649.8
W 6-7	R 1-1	11987.1	7584.4
W 7-1	R 1-1	10421.5	7384.9
W 7-2	R 1-1	10251.7	7274.6
W 9-1	R 1-1	10679.2	7574.7
W 9-2	R 1-1	3792.1	2851.9
W 9-3	R 1-1	10616.9	7537.9
W 8-1	R 1-1	5400.9	3775.1
W 8-2	R 1-1	5355.4	3742.9
W 8-3	R 1-1	5372.6	3753.6
W10-1	R 1-1	5776.8	4066.2
W10-2	R 1-1	0.0	0.0
W10-3	R 1-1	5511.5	3860.6
W10-4	R 1-1	5511.5	4175.3
W11-1	R 1-1	5551.6	3572.3
W11-2	R 1-1	1520.1	1151.9
W11-3	R 1-1	5519.0	3547.4
W12-1	R 1-1	10212.0	7238.2
W12-2	R 1-1	0.0	0.0
W13-1	R 1-1	8002.2	5738.4
W13-2	R 1-1	8588.9	6115.8
W13-3	R 1-1	0.0	0.0
W14-1	R 1-1	5010.6	3452.4
W14-2	R 1-1	0.0	0.0
W14-3	R 1-1	3609.3	2524.8
W14-4	R 1-1	5639.6	3788.9

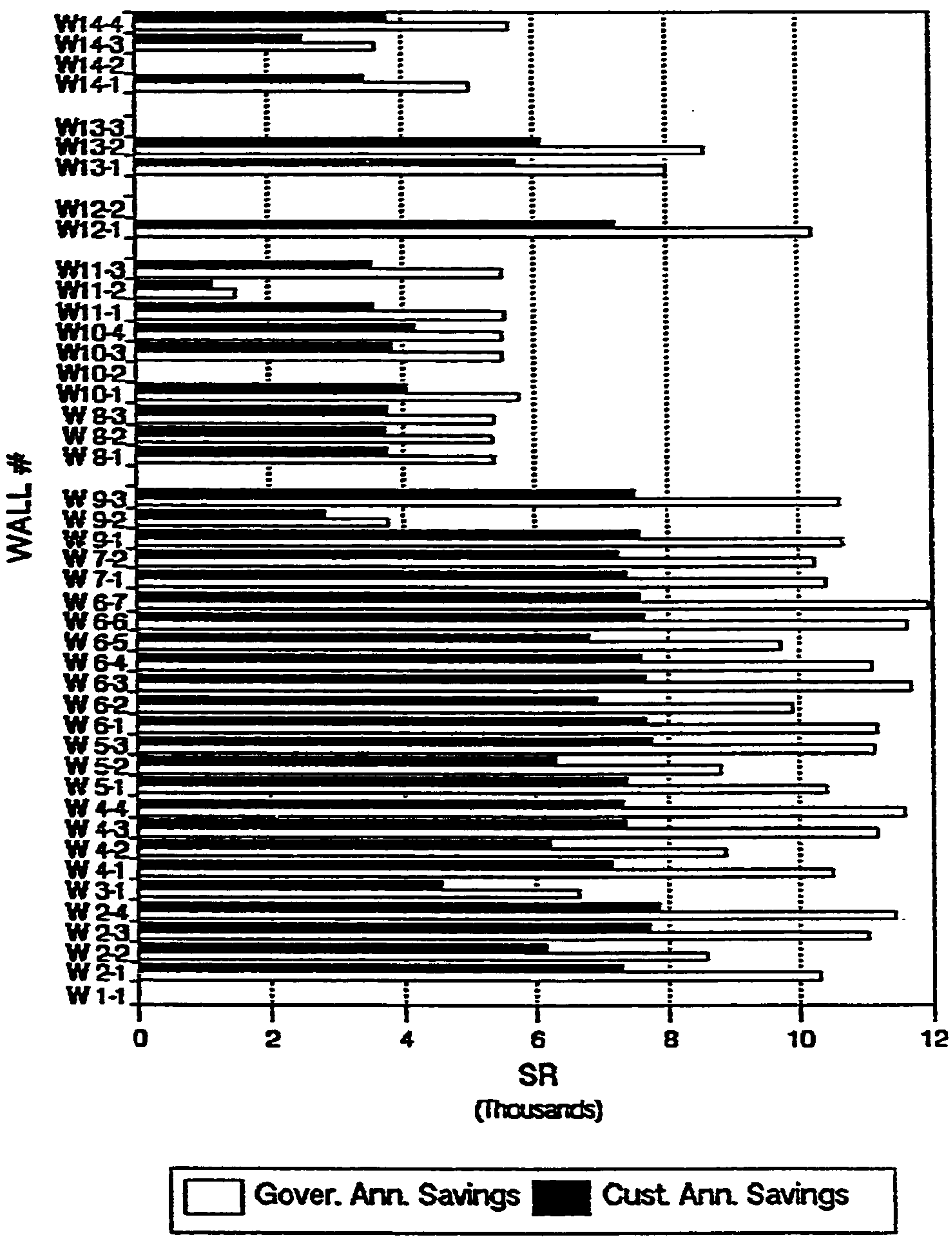


Figure 6.24: Riyadh - Annual savings (walls).

6.1.2.2 Economic performance of roofs

Table 6.5 shows the economic performance of roofs in Riyadh city. This is illustrated graphically in Figure 6.25.

This figure shows that for group 1, roof R2-8 (exterior 100mm expanded polystyrene) gives the maximum customer's annual savings. For the government, roofs R2-4 (exterior 100mm extruded polystyrene), R3-1 (exterior 75mm polyurethane) and R5-4 (interior 100mm extruded polystyrene) give the maximum government's annual savings.

In group 2, roof R7-4 (exterior 100mm expanded polystyrene) gives the highest savings in this group for both government and customers.

In group 3, roof R8-2 (interior 75mm fiberglass batt) gives the maximum savings for the customers. Roof R8-3 (interior 150mm fiberglass batt) gives the best government's annual savings.

In group 4, roof R9-1 (exterior 75mm extruded polystyrene) gives the maximum annual savings for the customers, while roof R9-2 (exterior 100mm extruded polystyrene) gives the highest annual savings for the government.

In group 5, roof R10-1 (exterior 75mm extruded polystyrene) gives the highest annual savings for the government and the customers.

In the last group, roof R11-3 (exterior 50mm extruded polystyrene) gives the maximum annual savings for the customers, while, roof R11-1 (exterior 75mm extruded polystyrene) gives the highest annual savings for the government.

Table 6.5: Riyadh - Annual savings (roofs).

WALL	ROOF	GOVERN. ANNUAL SAVINGS	CUSTOM. ANNUAL SAVINGS
W 1-1	R 1-1	0.0	0.0
W 1-1	R 2-1	5602.2	3513.8
W 1-1	R 2-2	4245.3	2881.6
W 1-1	R 2-3	5184.1	3408.2
W 1-1	R 2-4	5841.9	3486.0
W 1-1	R 2-5	5471.9	3549.5
W 1-1	R 2-6	4085.6	2763.8
W 1-1	R 2-7	5025.9	3373.0
W 1-1	R 2-8	5732.6	3582.8
W 1-1	R 3-1	5850.8	2981.2
W 1-1	R 4-1	5602.1	3514.0
W 1-1	R 4-2	5583.8	3503.2
W 1-1	R 4-3	5546.5	3471.4
W 1-1	R 5-1	5594.4	3325.6
W 1-1	R 5-2	4229.1	2689.5
W 1-1	R 5-3	5172.9	3212.8
W 1-1	R 5-4	5836.2	3296.5
W 1-1	R 6-1	0.0	0.0
W 1-1	R 7-1	5217.6	3337.4
W 1-1	R 7-2	3818.6	2578.4
W 1-1	R 7-3	4760.1	3151.9
W 1-1	R 7-4	5465.5	3352.6
W 1-1	R 8-1	3652.8	1147.3
W 1-1	R 8-2	3388.4	1326.7
W 1-1	R 8-3	3961.1	610.9
W 1-1	R 8-4	0.0	0.0
W 1-1	R 9-1	5776.1	3558.1
W 1-1	R 9-2	6074.2	3460.2
W 1-1	R 9-3	0.0	0.0
W 1-1	R10-1	8638.8	5594.8
W 1-1	R10-2	0.0	0.0
W 1-1	R10-3	8149.8	5522.4
W 1-1	R11-1	1940.5	575.2
W 1-1	R11-2	0.0	0.0
W 1-1	R11-3	1686.6	686.5

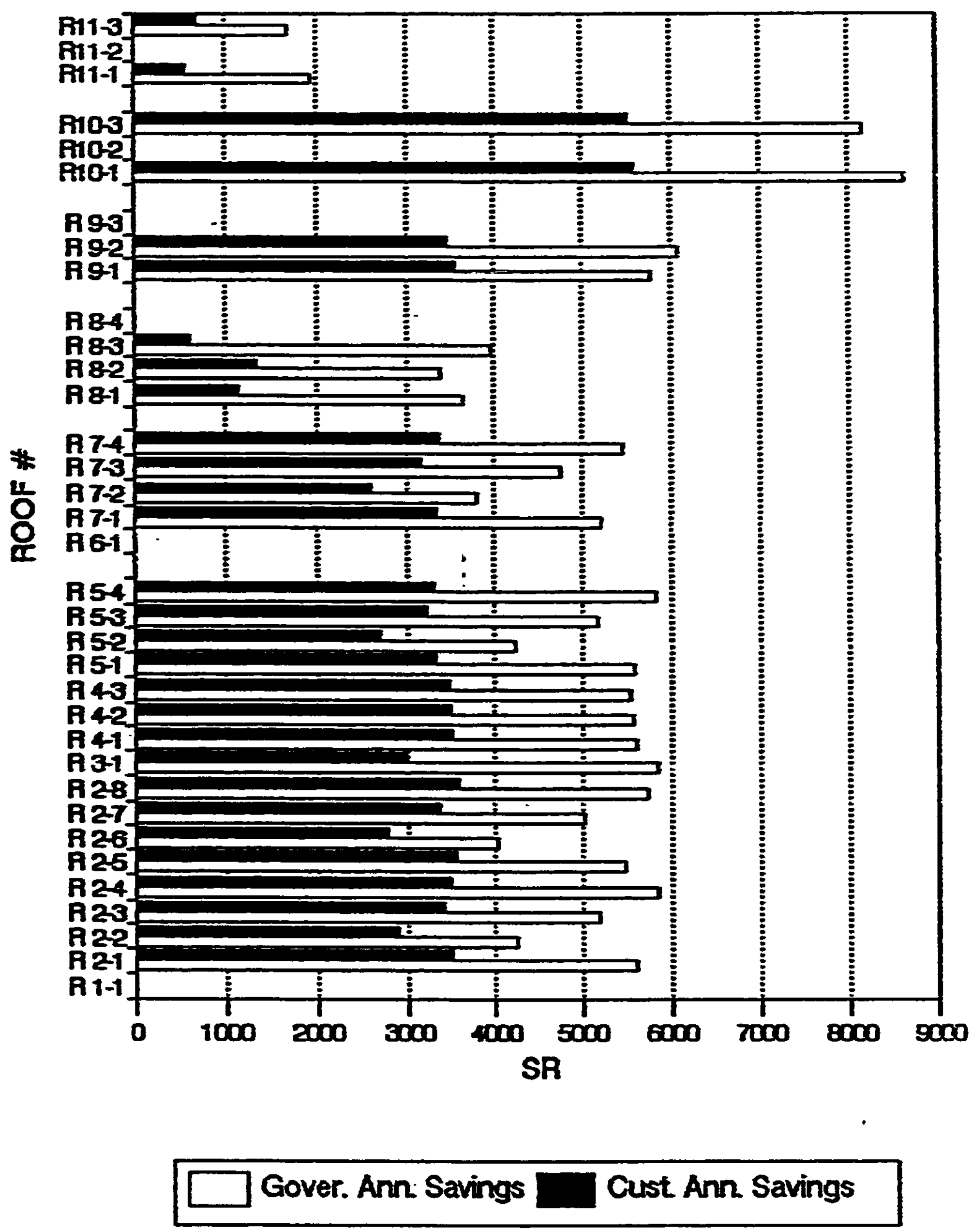


__Figure 6.25__: Riyadh - Annual savings (roofs).

6.1.2.3 Combined performance

Figure 6.26 shows the government and customer's annual savings for the combination insulation case in Riyadh city. From this bar chart, it is clear that the combinations of W2-3 R2-1 (interior 75mm expanded polystyrene on a CMU wall and exterior 75mm extruded polystyrene on a reinforced concrete roof), and W5-3 R2-1 (exterior 75mm expanded polystyrene on a CMU wall and exterior 75mm extruded polystyrene on a reinforced concrete roof) give the maximum customer's annual savings. For the government, the combinations of W2-3 R2-4 (interior 75mm expanded polystyrene on a CMU wall and exterior 100mm extruded polystyrene on a reinforced concrete roof) and W5-3 R2-4 (exterior 75mm expanded polystyrene on a CMU wall and exterior 100mm extruded polystyrene on a reinforced concrete roof) will give the highest government's annual savings.

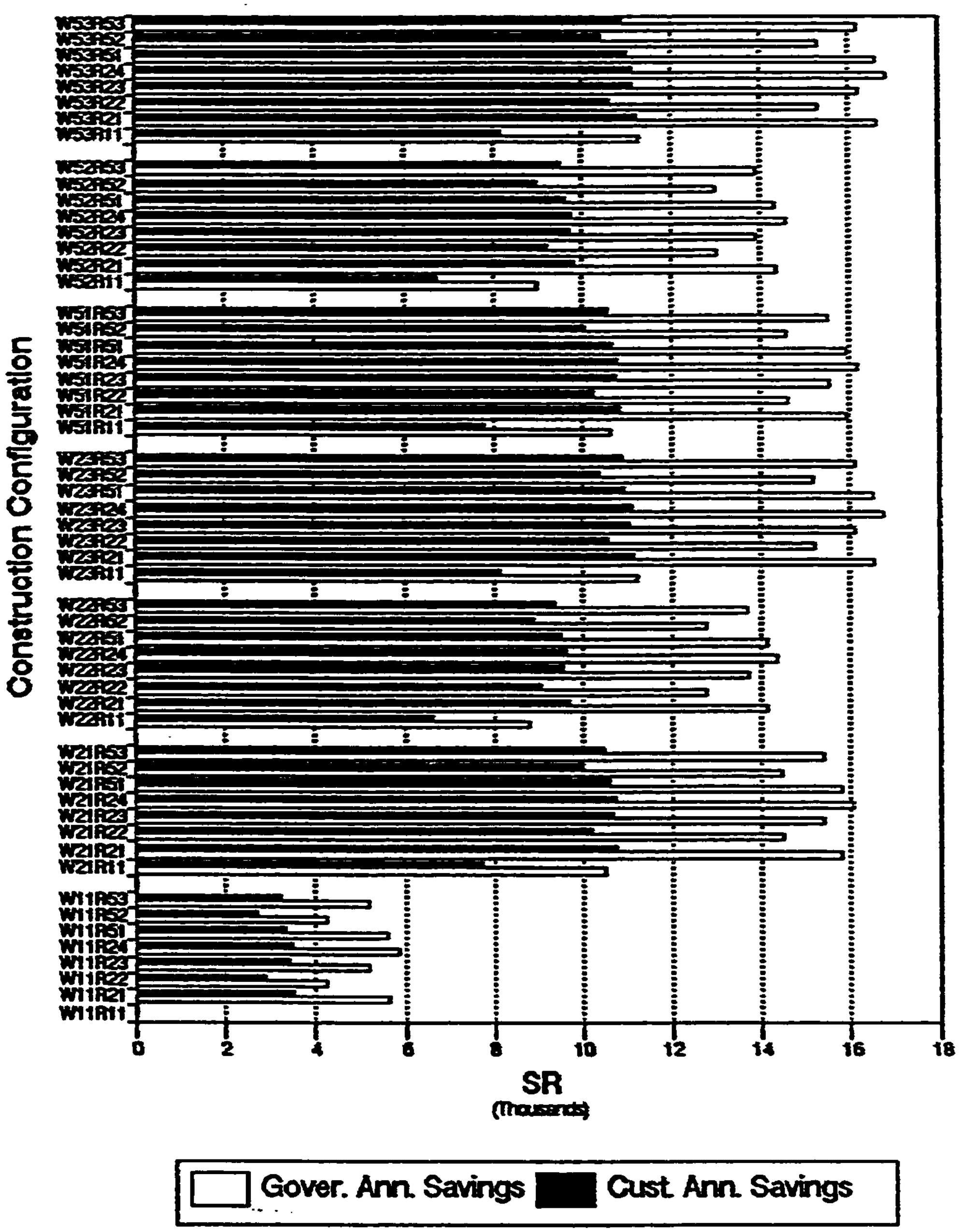


Figure 6.26: Riyadh - Annual savings (combinations).

6.1.2.4 Optimization graphs

Figures 6.27 through 6.30 illustrate the economic performance of each material among its group for both walls and roofs. From these figures, the following can be seen:

- Figure 6.27 shows that the expanded polystyrene board when used on the interior of on the CMU wall will give the best economic performance, especially for thicknesses greater than 50mm. For thicknesses less than 50mm, the polyurethane board when used on the exterior will show the best performance.
- Figure 6.28 shows that among the rest of the walls groups (groups 2 to 5) in Riyadh city, the interior expanded polystyrene on the split faced block wall will show the best economic performance.
- Figure 6.29 shows that among group 1 of the roofs in Riyadh, the expanded polystyrene when used on the exterior of a reinforced concrete roof will give the highest customer's annual savings.
- Figure 6.30 shows that the extruded polystyrene when used on the exterior of a precast hollow core roof will show the best economic performance among the roof's groups 2 to 6.

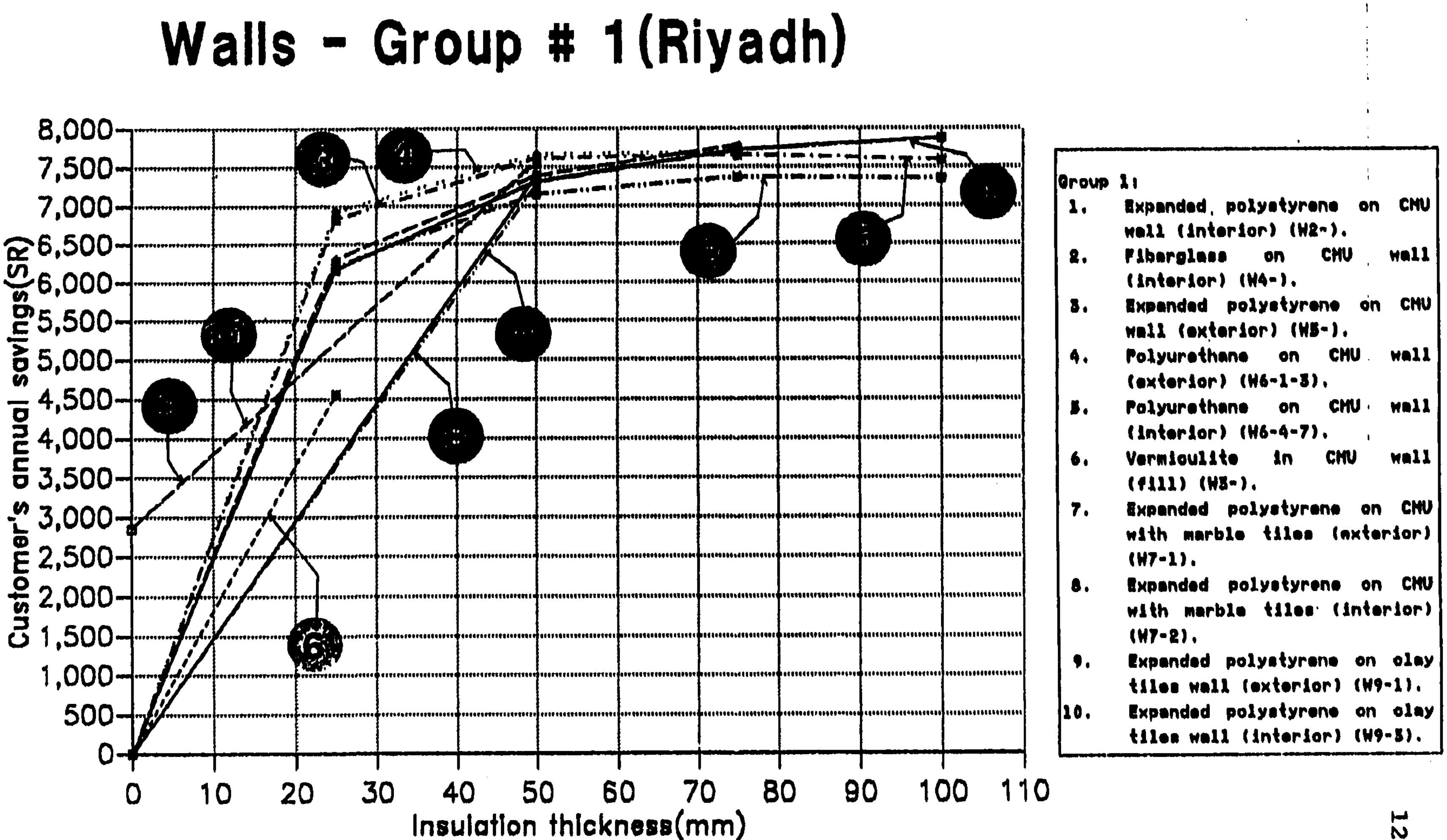
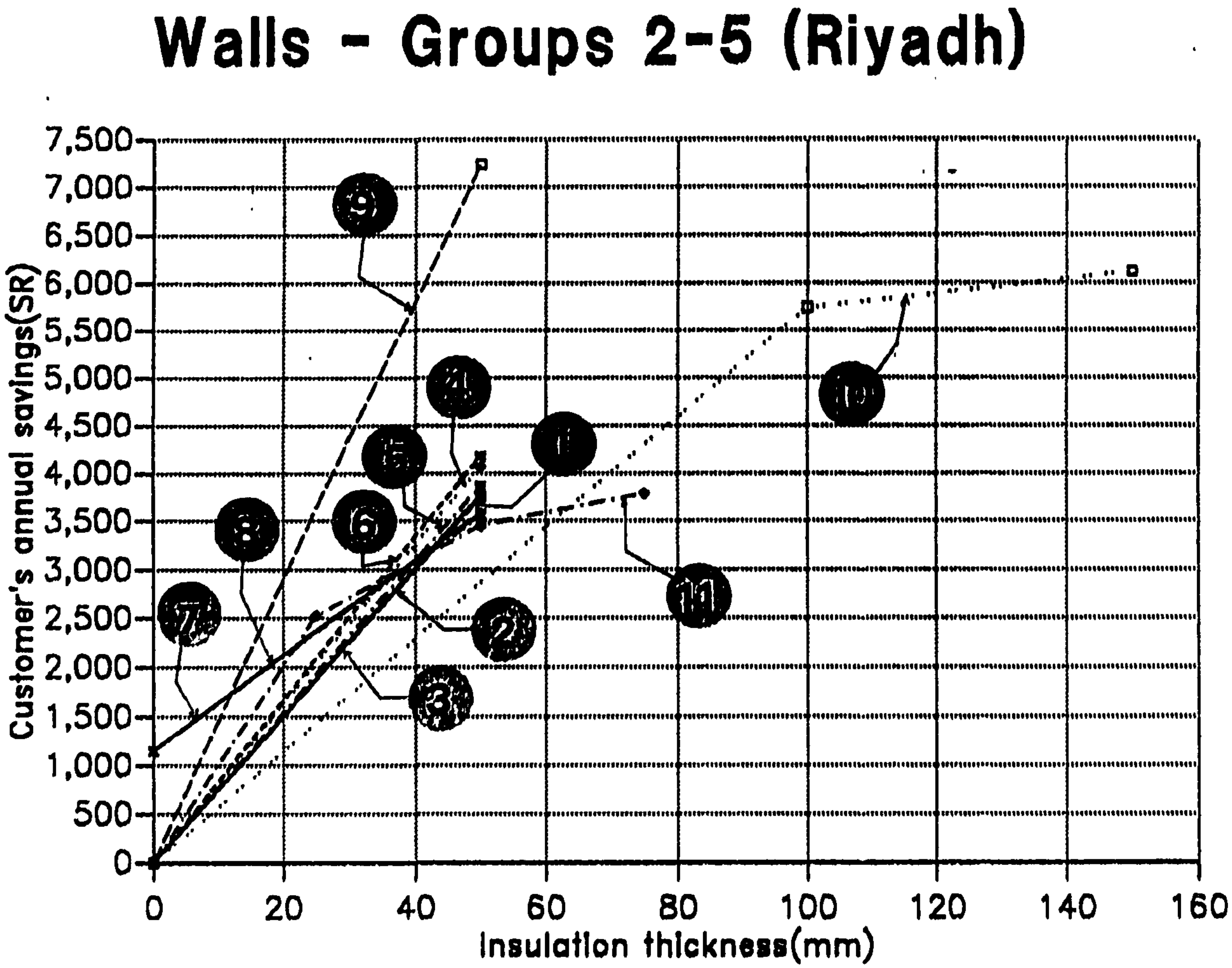


Figure 6.27: Riyadh - Walls # 1 (Economic performance).



Group 2:
1. Expanded polystyrene in CMU and brick wall (exterior) (W8-1).
2. Expanded polystyrene in CMU and brick wall (interior) (W8-2).
3. Expanded polystyrene with airspace in CMU and brick wall (interior) (W8-3).
4. Fiberglass with reflective airspace in CMU and brick wall (exterior) (W10-1).
5. Fiberglass in CMU and brick wall (interior) (W10-3).
6. Fiberglass with no reflective airspace in CMU and brick wall (exterior) (W10-4).
7. Expanded polystyrene in clay tiles and brick wall (exterior) (W11-1).
8. Expanded polystyrene in clay tiles and brick wall (interior) (W11-3).

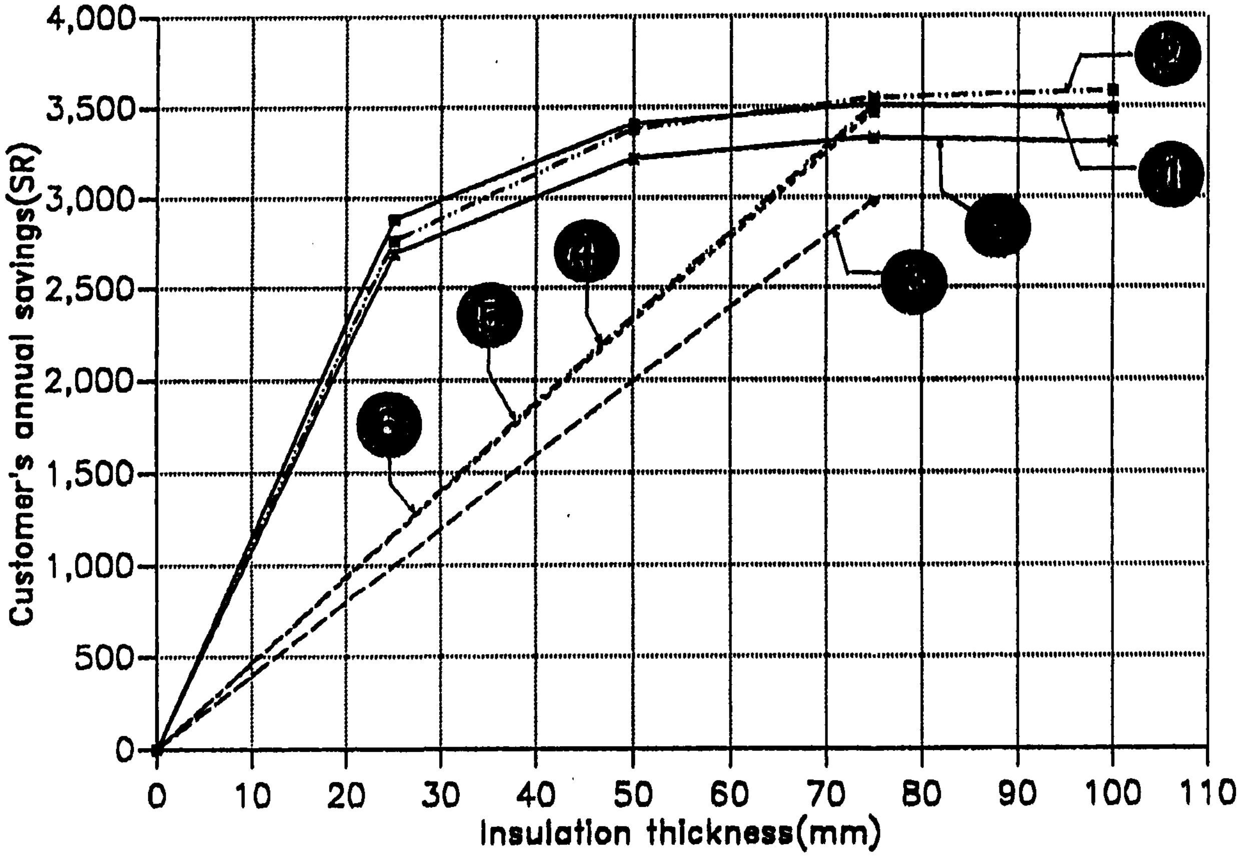
Group 3:
9. Expanded polystyrene on split faced block (interior) (W12-).

Group 4:
10. Fiberglass batt in metal studs (W13-).

Group 5:
11. Expanded polystyrene in cavity of two solid CMU walls (W14-).

Figure 6.28: Riyadh - Walls # 2 - 5 (Economic performance).

Roofs - Group # 1(Riyadh)



Group 1:

1. Extruded polystyrene on reinforced concrete roof (exterior) (R2-1-4).
2. Expanded polystyrene on reinforced concrete roof (exterior) (R2-5-6).
3. Polyurethane on reinforced concrete roof (exterior) (R3-1).
4. Extruded polystyrene on inverted reinforced concrete roof (exterior) (R4-1).
5. Extruded polystyrene on inverted reinforced concrete roof without mortar (exterior) (R4-2).
6. Extruded polystyrene on inverted reinforced concrete roof without mortar and sand (exterior) (R4-3).
7. Extruded polystyrene on reinforced concrete roof (interior) (R5-).

Figure 6.29: Riyadh - Roofs # 1 (Economic performance).

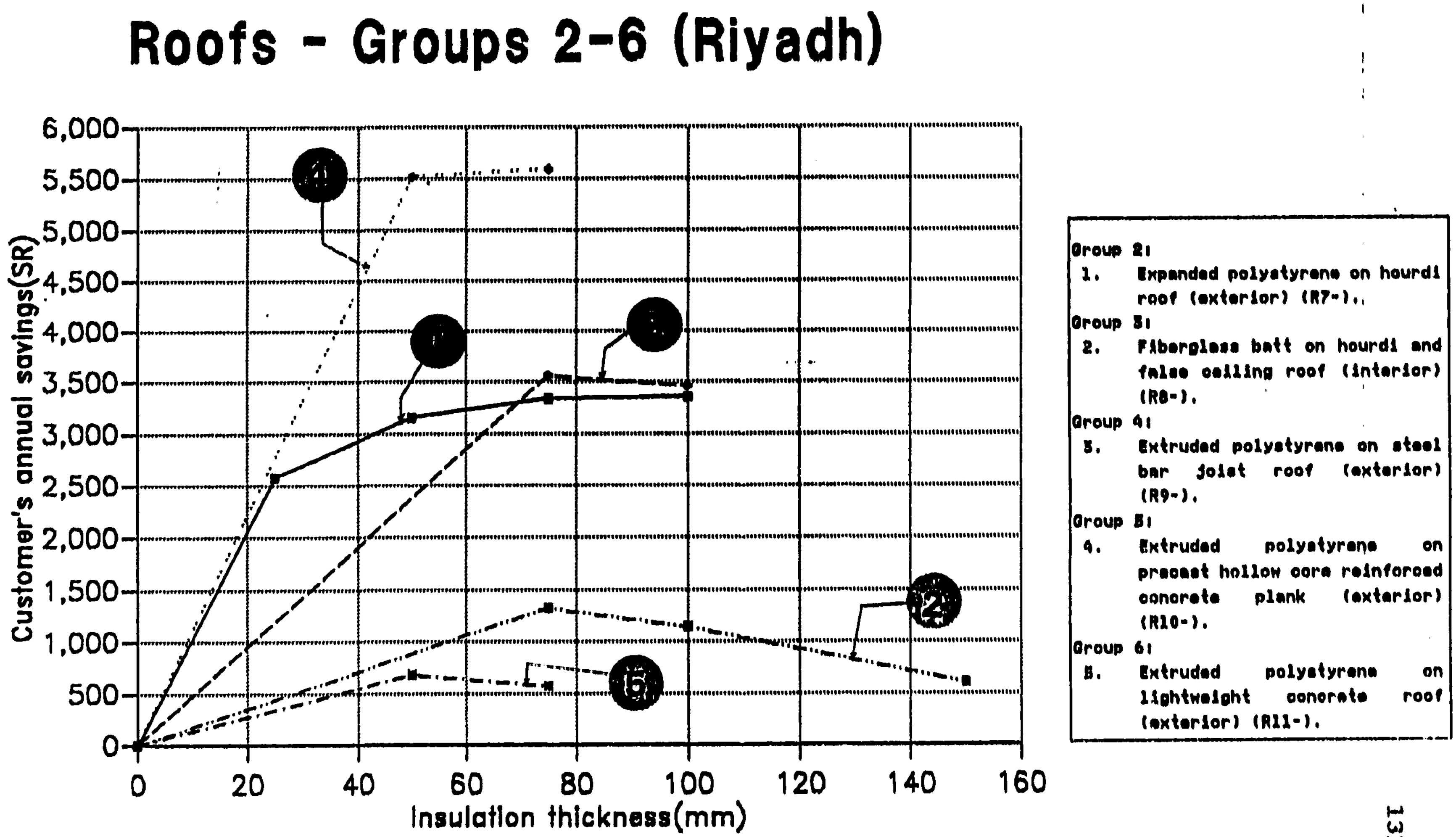


Figure 6.30: Riyadh - Roofs # 2 - 6 (Economic performance).

6.1.2.5 Wall and roof U-values (Customers)

The thermal performance of each variation within a group of walls or roofs versus the customer's annual savings is represented in the following figures, Figures 6.31 to 6.34. The extracted U-values from these figures are summarized in section 6.2.

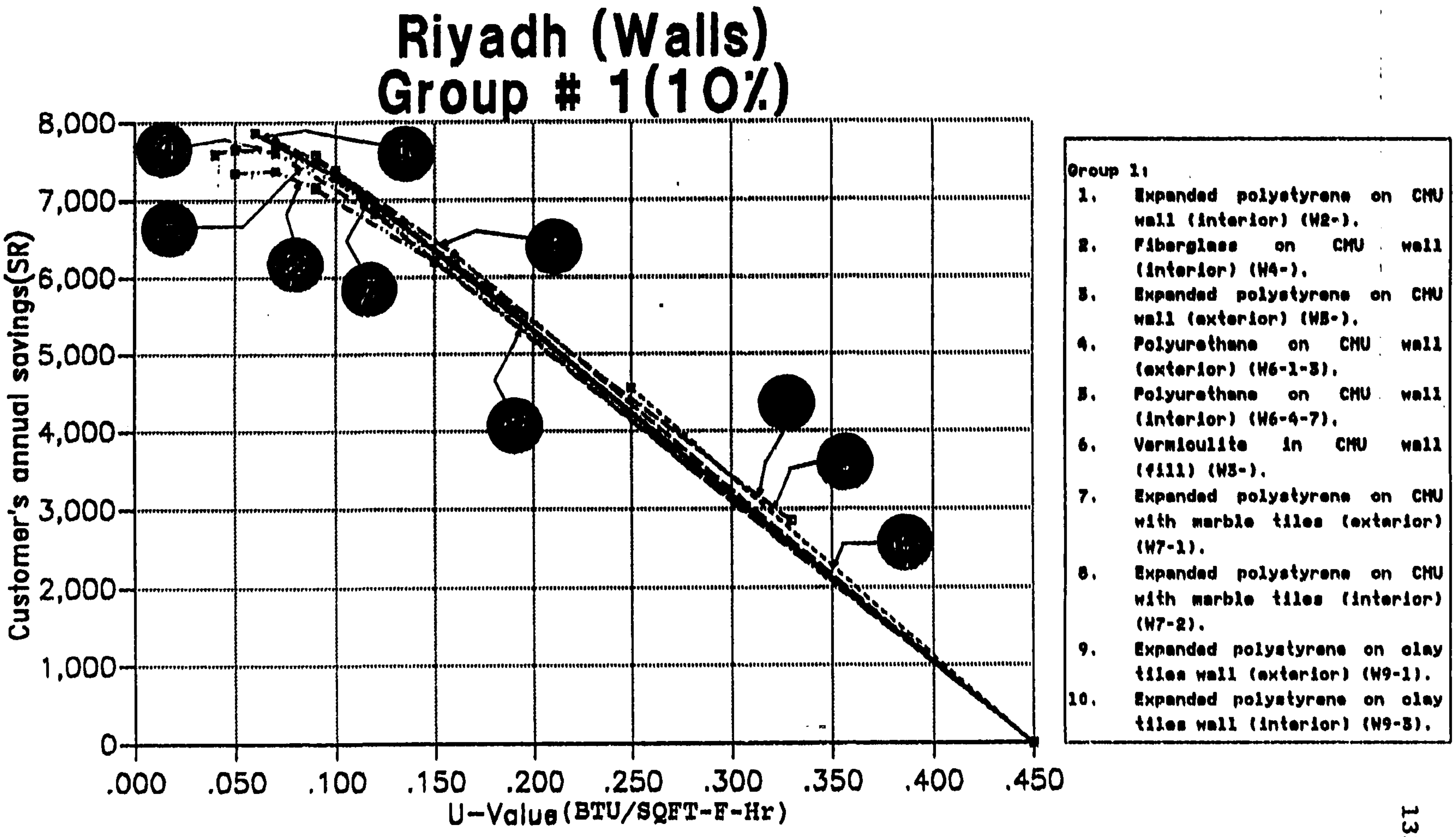
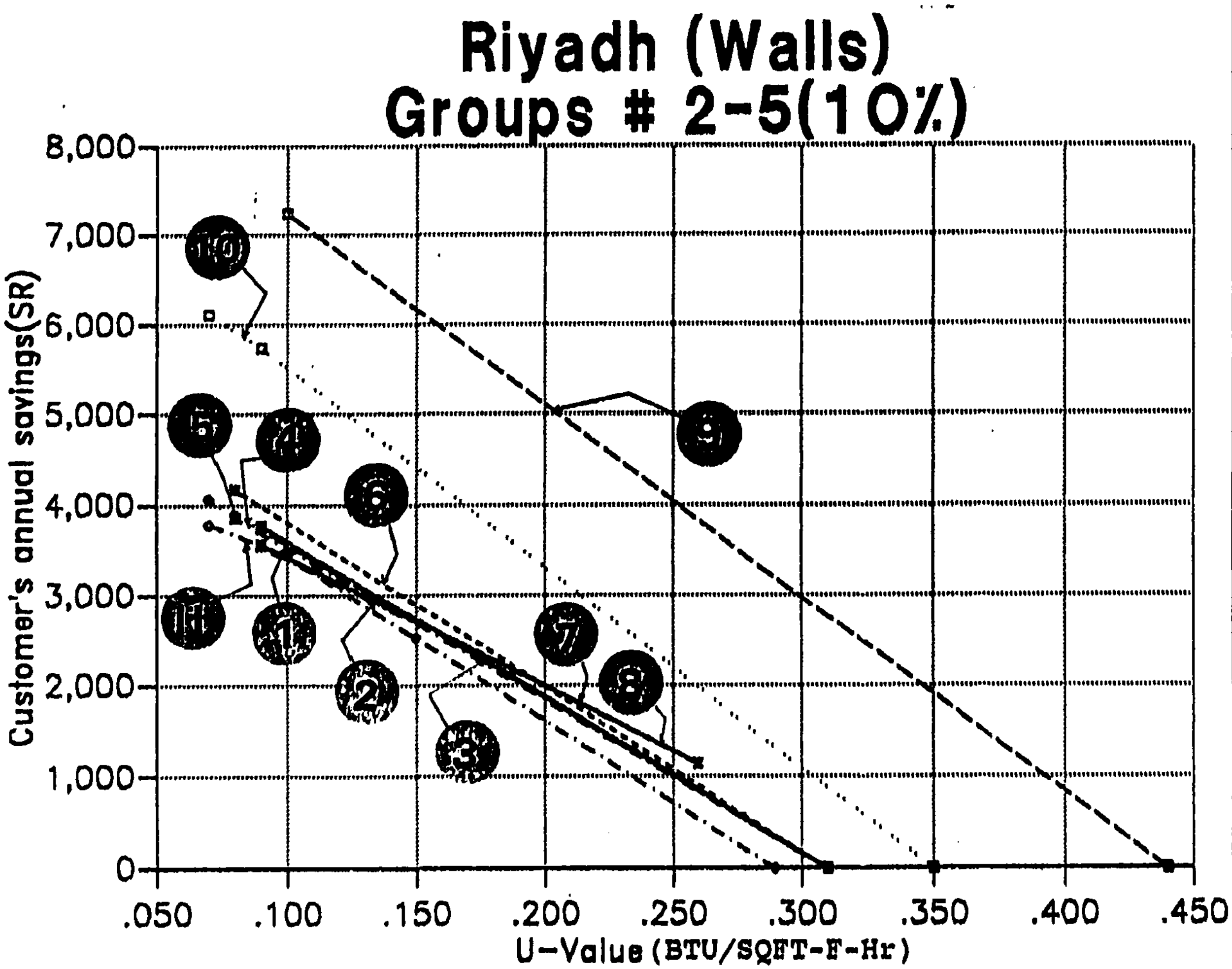


Figure 6.31: Riyadh - Walls # 1 (Thermal performance (customer)).



Group 2:
1. Expanded polystyrene in CMU and brick wall (exterior) (W8-1).
2. Expanded polystyrene in CMU and brick wall (interior) (W8-2).
3. Expanded polystyrene with airspace in CMU and brick wall (interior) (W8-3).
4. Fiberglass with reflective airspace in CMU and brick wall (exterior) (W10-1).
5. Fiberglass in CMU and brick wall (interior) (W10-3).
6. Fiberglass with no reflective airspace in CMU and brick wall (exterior) (W10-4).
7. Expanded polystyrene in clay tiles and brick wall (exterior) (W11-1).
8. Expanded polystyrene in clay tiles and brick wall (interior) (W11-3).

Group 3:
9. Expanded polystyrene on split faced block (interior) (W12-).

Group 4:
10. Fiberglass batt in metal studs (W13-).

Group 5:
11. Expanded polystyrene in cavity of two solid CMU walls (W14-).

Figure 6.32: Riyadh - Walls # 2 -5 (Thermal performance (customer)).

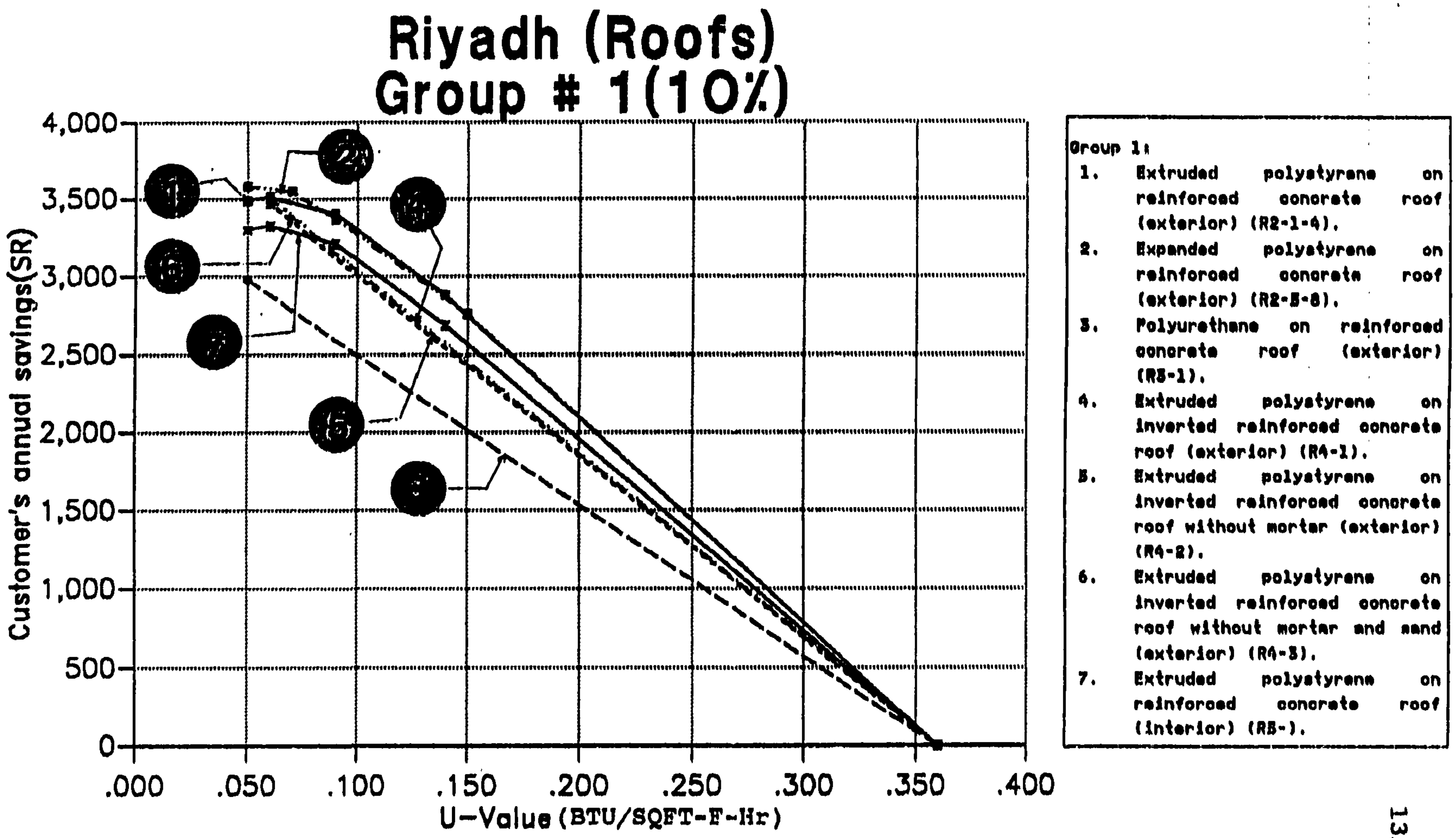


Figure 6.33: Riyadh - Roofs # 1 (Thermal performance (customer)).

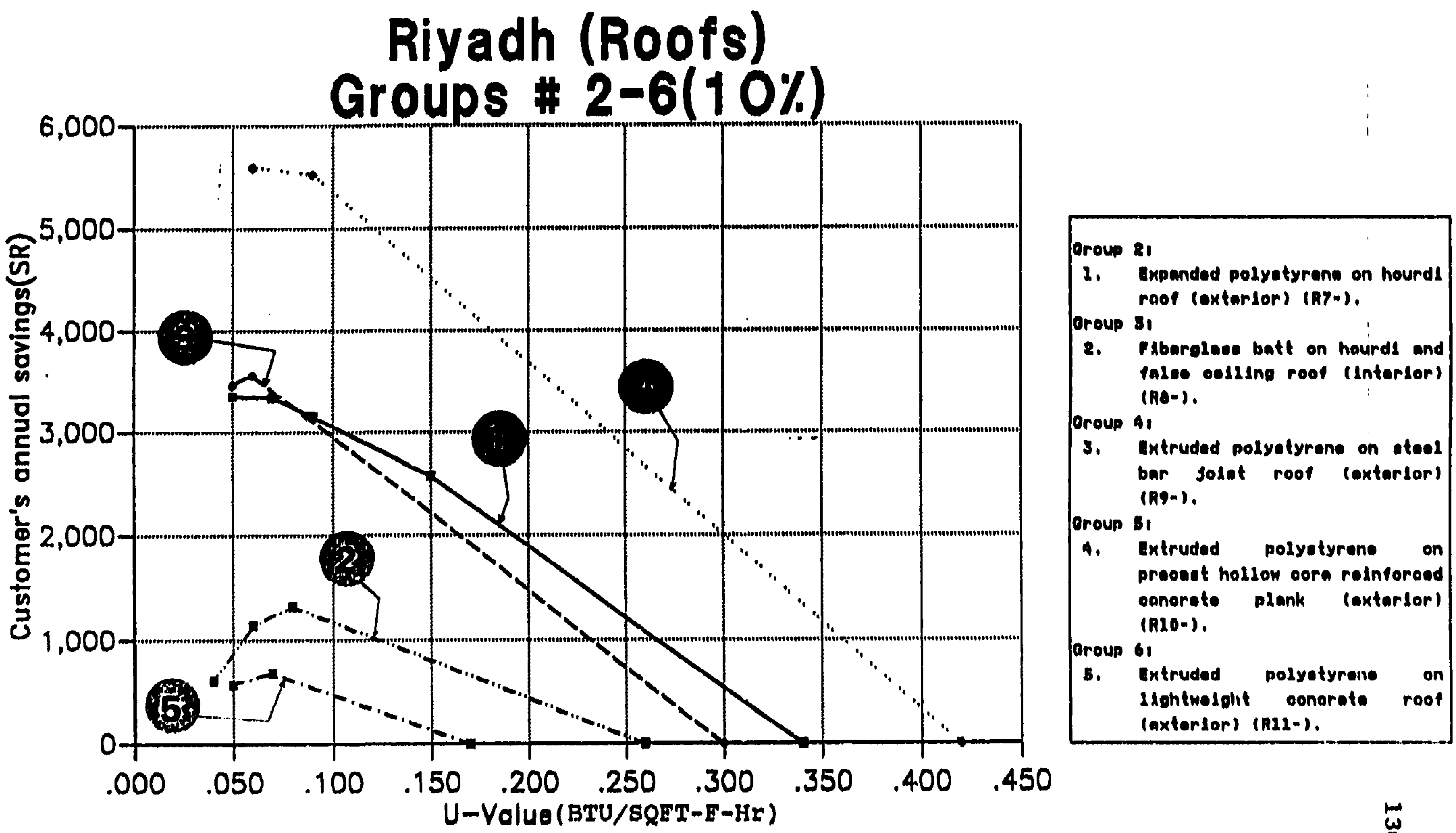


Figure 6.34: Riyadh - Roofs # 2 - 6 (Thermal performance (customer)).

6.1.2.6 Wall and roof U-values (Government)

The thermal performance of each variation within a group of walls or roofs versus government's annual savings is represented in the following figures, Figures 6.35 to 6.38. The extracted U-values from these figures are summarized in section 6.2.

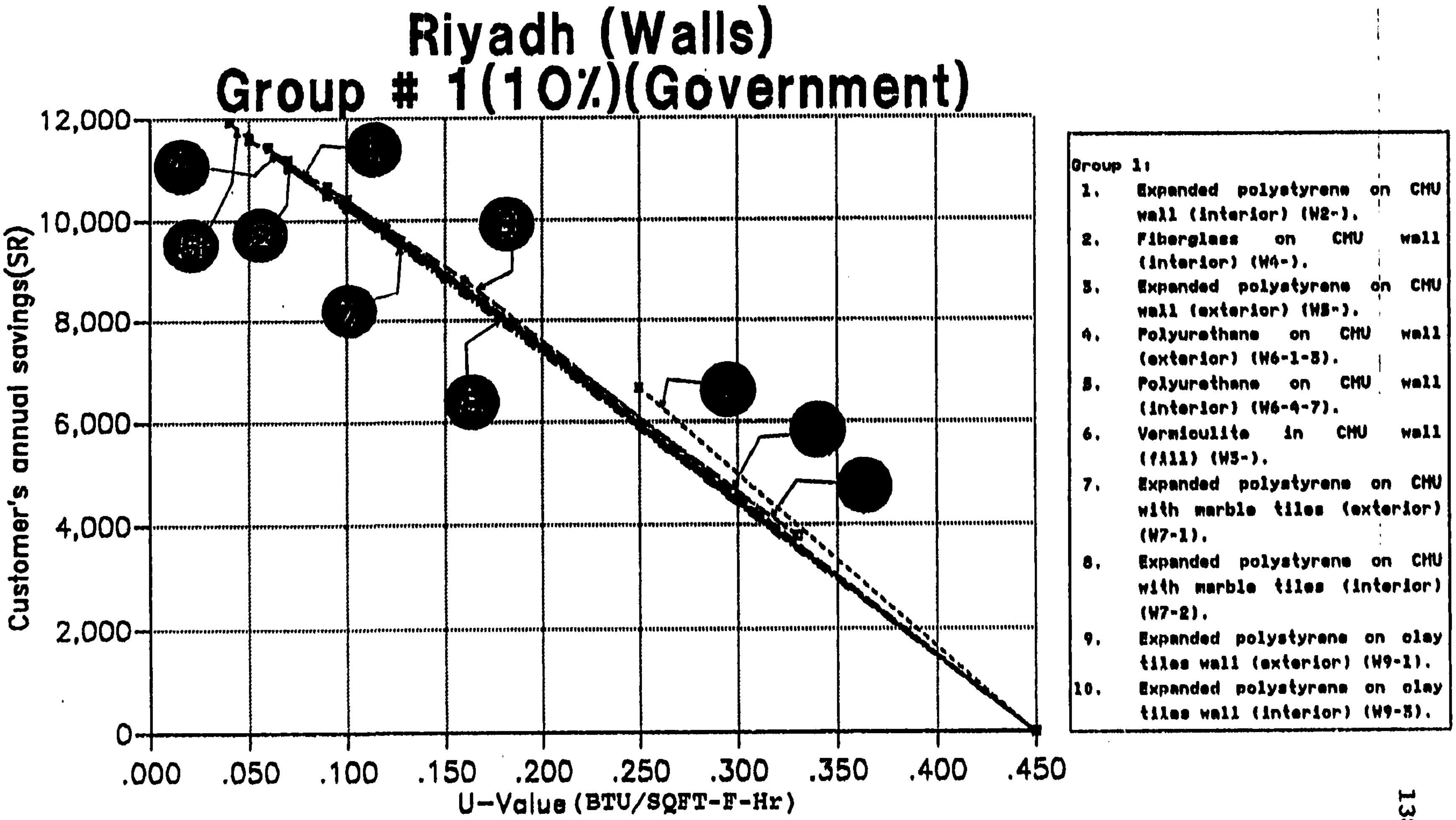
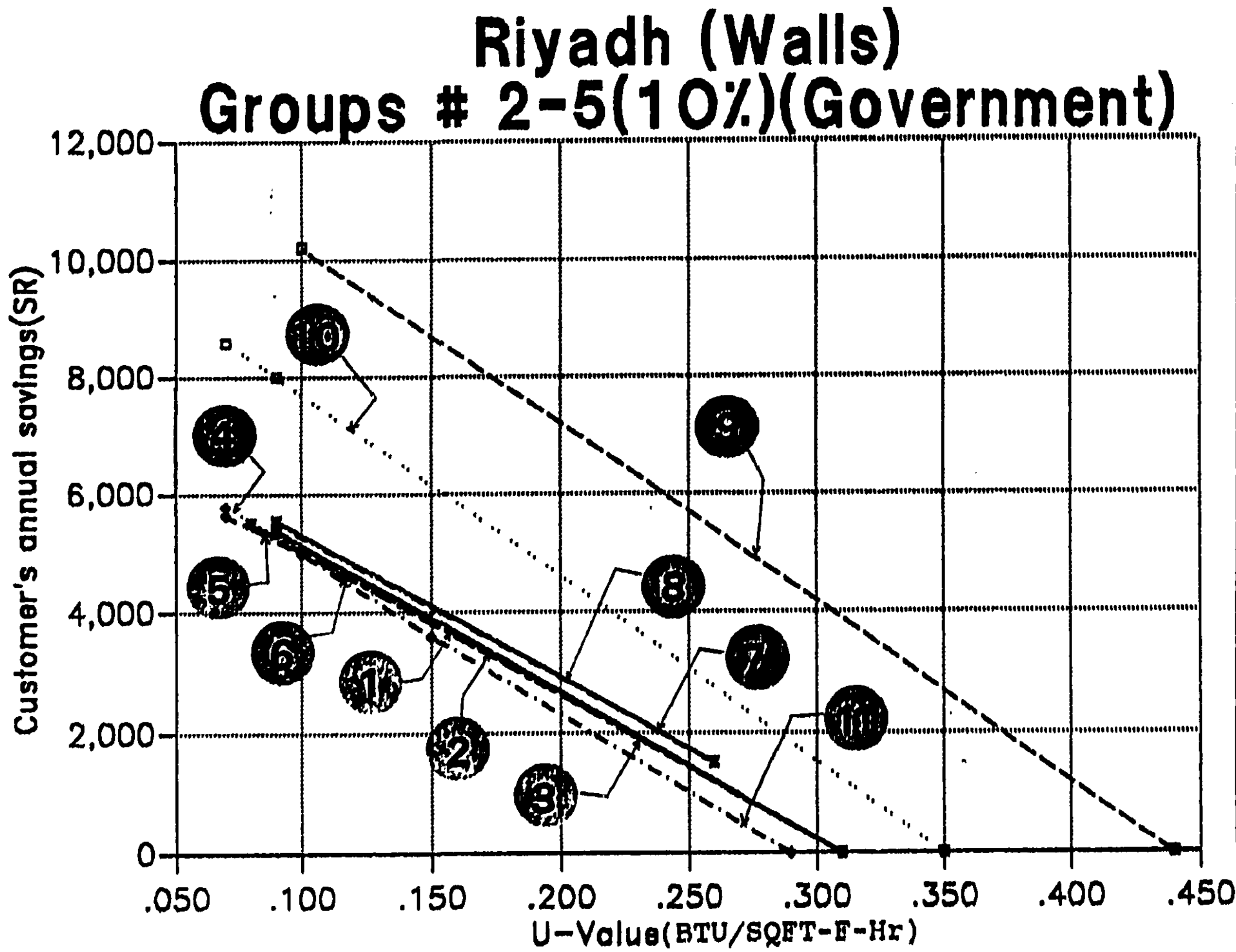


Figure 6.35: Riyadh - Walls # 1 (Thermal performance (government)).



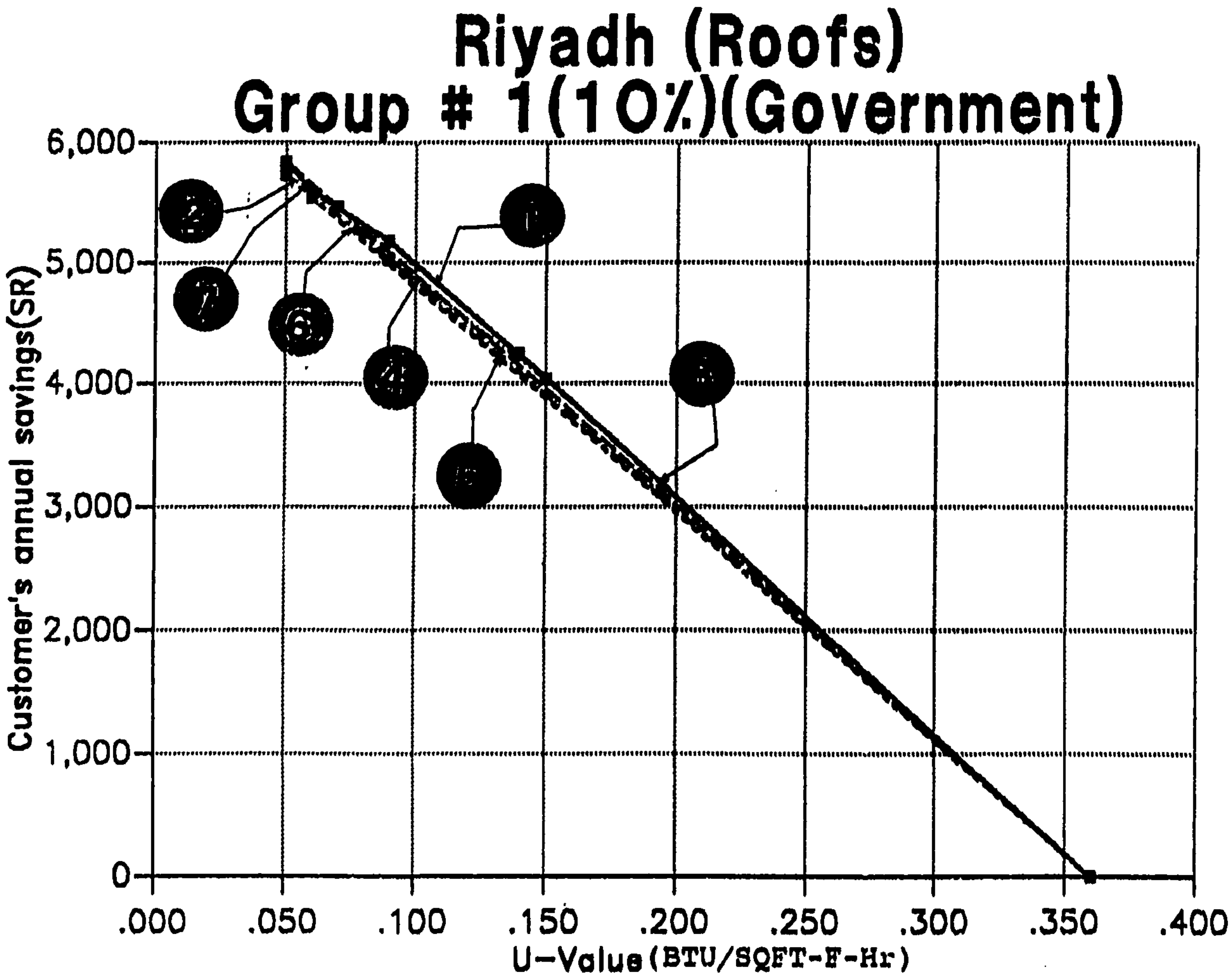
Group 2:
1. Expanded polystyrene in CMU and brick wall (exterior) (W8-1).
2. Expanded polystyrene in CMU and brick wall (interior) (W8-2).
3. Expanded polystyrene with airspace in CMU and brick wall (interior) (W8-3).
4. Fiberglass with reflective airspace in CMU and brick wall (exterior) (W10-1).
5. Fiberglass in CMU and brick wall (interior) (W10-3).
6. Fiberglass with no reflective airspace in CMU and brick wall (exterior) (W10-4).
7. Expanded polystyrene in clay tiles and brick wall (exterior) (W11-1).
8. Expanded polystyrene in clay tiles and brick wall (interior) (W11-3).

Group 3:
9. Expanded polystyrene on split faced block (interior) (W12-).

Group 4:
10. Fiberglass batt in metal studs (W13-).

Group 5:
11. Expanded polystyrene in cavity of two solid CMU walls (W14-).

Figure 6.36: Riyadh - Walls # 2 -5 (Thermal performance (government)).



Group 1:

1. Extruded polystyrene on reinforced concrete roof (exterior) (R2-1-4).
2. Expanded polystyrene on reinforced concrete roof (exterior) (R2-5-6).
3. Polyurethane on reinforced concrete roof (exterior) (R3-1).
4. Extruded polystyrene on inverted reinforced concrete roof (exterior) (R4-1).
5. Extruded polystyrene on inverted reinforced concrete roof without mortar (exterior) (R4-2).
6. Extruded polystyrene on inverted reinforced concrete roof without mortar and sand (exterior) (R4-3).
7. Extruded polystyrene on reinforced concrete roof (interior) (R5-).

Figure 6.37: Riyadh - Roofs # 1 (Thermal performance (government)).

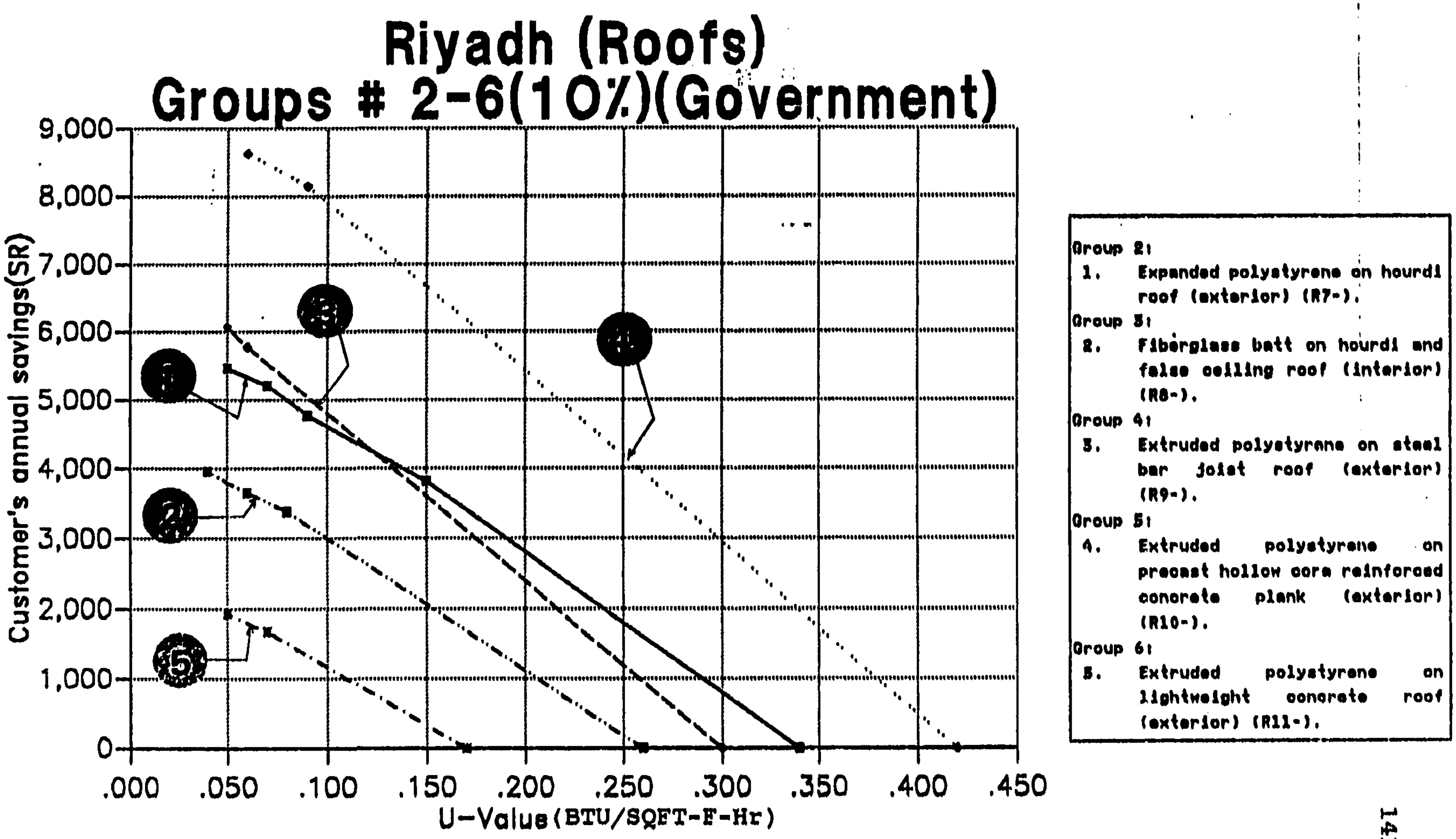


Figure 6.38: Riyadh - Roofs # 2 - 6 (Thermal performance (government)).

6.1.3 Jeddah city

6.1.3.1 Economic performance of walls

Table 6.6 lists the annual savings for the government and the customers for wall configurations in Jeddah city. The graph illustration of these results is shown in Figure 6.39.

Figure 6.39 shows that wall W2-4 (interior 100mm expanded polystyrene board) gives the best savings among group 1 for the customers. For the government, wall W6-7 (interior 100mm polyurethane board) will give the highest annual savings.

In group 2, wall W10-4 (exterior 50mm fiberglass with no reflective airspace) gives the best savings among the group for the government, while wall W10-1 (exterior 50mm fiberglass with reflective airspace) gives the best savings for the customers.

In group 3, wall W12-1 (interior 50mm expanded polystyrene) gives the best savings for both government and customers.

In group 4, wall W13-2 (150mm fiberglass batt) gives the best saving among its group for both government and customers.

Finally, in group 5, wall W14-4 (cavity 75mm expanded polystyrene) gives the highest savings in its group for both government and customers.

Table 6.6: Jeddah - Annual savings (walls).

WALL	ROOF	GOVERN. ANNUAL SAVINGS	CUSTOM. ANNUAL SAVINGS
W 1-1	R 1-1	0.0	0.0
W 2-1	R 1-1	7856.7	5346.4
W 2-2	R 1-1	6536.1	4518.6
W 2-3	R 1-1	8438.3	5633.5
W 2-4	R 1-1	8760.5	5719.4
W 3-1	R 1-1	4894.5	3250.9
W 4-1	R 1-1	8019.7	5165.9
W 4-2	R 1-1	6740.3	4512.0
W 4-3	R 1-1	8559.5	5256.9
W 4-4	R 1-1	8868.4	5177.3
W 5-1	R 1-1	7977.2	5441.5
W 5-2	R 1-1	6704.7	4628.1
W 5-3	R 1-1	8517.1	5680.5
W 6-1	R 1-1	8559.6	5584.2
W 6-2	R 1-1	7547.7	5063.3
W 6-3	R 1-1	8958.9	5510.7
W 6-4	R 1-1	8481.6	5526.4
W 6-5	R 1-1	7411.1	4964.0
W 6-6	R 1-1	8904.3	5467.1
W 6-7	R 1-1	9144.8	5351.6
W 7-1	R 1-1	7971.7	5430.0
W 7-2	R 1-1	7828.0	5333.0
W 9-1	R 1-1	8168.6	5582.7
W 9-2	R 1-1	2814.1	2081.0
W 9-3	R 1-1	8101.9	5531.5
W 8-1	R 1-1	4261.5	2824.3
W 8-2	R 1-1	4250.0	2797.4
W 8-3	R 1-1	4243.8	2805.3
W10-1	R 1-1	4555.9	3044.4
W10-2	R 1-1	0.0	0.0
W10-3	R 1-1	4358.5	2896.6
W10-4	R 1-1	4358.5	3211.3
W11-1	R 1-1	4390.7	2909.6
W11-2	R 1-1	1189.0	890.6
W11-3	R 1-1	4394.1	2632.2
W12-1	R 1-1	7796.8	5302.5
W12-2	R 1-1	0.0	0.0
W13-1	R 1-1	5808.2	3929.9
W13-2	R 1-1	6243.7	4191.0
W13-3	R 1-1	0.0	0.0
W14-1	R 1-1	3947.6	2577.4
W14-2	R 1-1	0.0	0.0
W14-3	R 1-1	2828.5	1877.1
W14-4	R 1-1	4450.3	2810.6

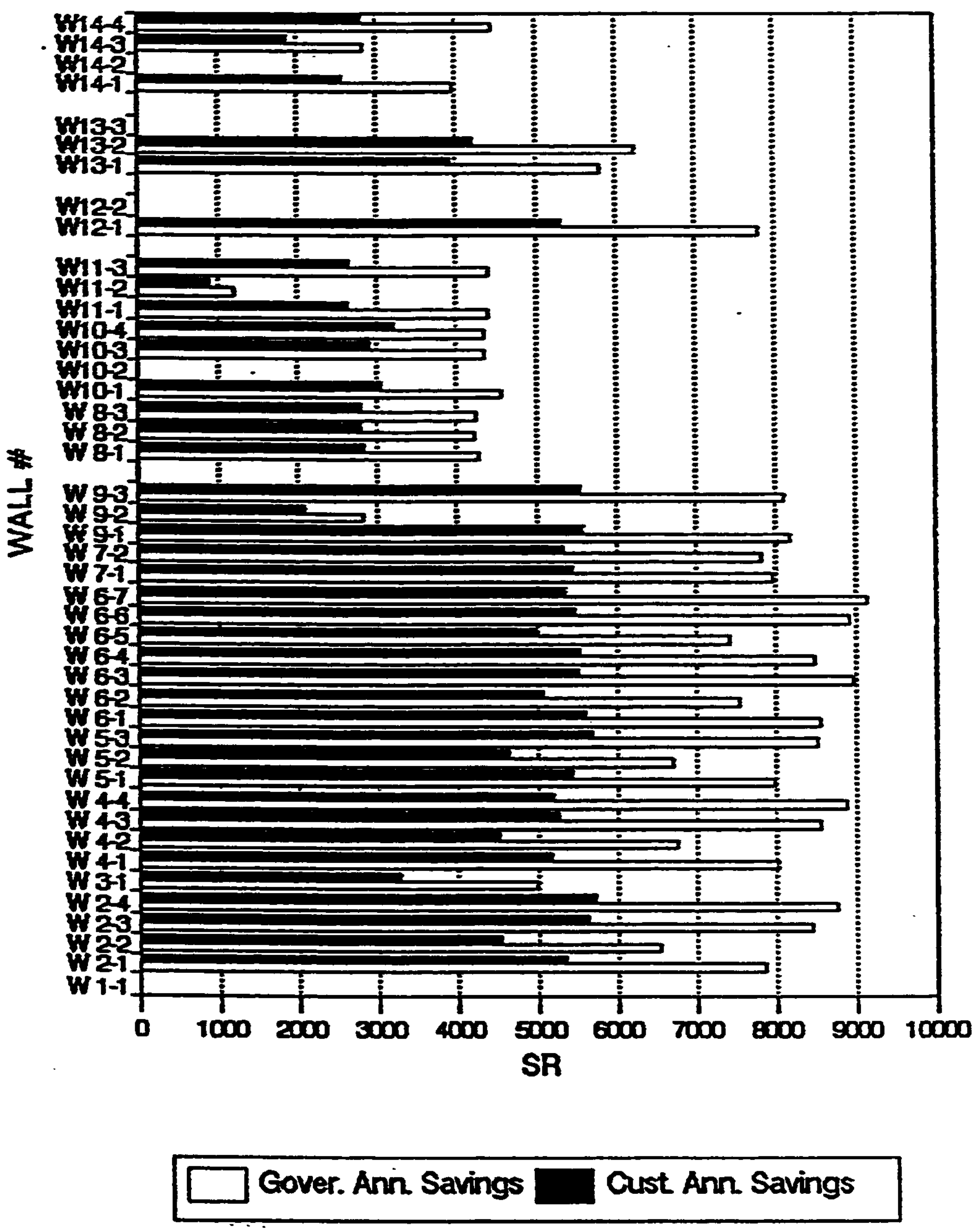


Figure 6.39: Jeddah - Annual savings (walls).

6.1.3.2 Economic performance of roofs

Table 6.7 shows the economic performance of roofs in Jeddah city. This is illustrated graphically in Figure 6.40.

This figure shows that for group 1, roof R2-5 (exterior 75mm expanded polystyrene) gives the maximum customer's annual savings, while roofs R2-4 (exterior 100mm extruded polystyrene) and R3-1 (exterior 75mm polyurethane) give the maximum government's annual savings.

In group 2, roof R7-1 (exterior 75mm expanded polystyrene) gives the highest savings in this group for the customers, while roof R7-4 (exterior 100mm expanded polystyrene) will give the maximum savings for the government.

In group 3, roof R8-2 (interior 75mm fiberglass batt) gives savings for the customers. Roof R8-3 (interior 150mm fiberglass batt) gives the best government's annual saving.

In group 4, roof R9-1 (exterior 75mm extruded polystyrene) gives the maximum annual savings for the customers, while roof R9-2 (exterior 100mm extruded polystyrene) gives the highest annual savings for the government.

In group 5, roof R10-3 (exterior 50mm extruded polystyrene) gives the highest annual savings for the customer's, while roof R10-1 (exterior 75mm extruded polystyrene) gives the highest annual savings for the government.

In the last group, roof R11-3 (exterior 50mm extruded polystyrene board) will give the maximum customer's annual savings, while roof R11-1 (exterior 75mm extruded polystyrene) gives the highest annual savings for the government.

Table 6.7: Jeddah - Annual savings (roofs).

WALL	ROOF	GOVERN. ANNUAL SAVINGS	CUSTOM. ANNUAL SAVINGS
W 1-1	R 1-1	0.0	0.0
W 1-1	R 2-1	4357.6	2433.4
W 1-1	R 2-2	3323.4	2084.9
W 1-1	R 2-3	4048.7	2426.2
W 1-1	R 2-4	4545.1	2363.5
W 1-1	R 2-5	4265.3	2508.0
W 1-1	R 2-6	3158.7	2002.8
W 1-1	R 2-7	3920.7	2418.8
W 1-1	R 2-8	4464.7	2488.0
W 1-1	R 3-1	4551.8	1857.0
W 1-1	R 4-1	4357.3	2433.4
W 1-1	R 4-2	4346.1	2429.5
W 1-1	R 4-3	4326.6	2420.8
W 1-1	R 5-1	4339.7	2232.6
W 1-1	R 5-2	3276.6	1849.9
W 1-1	R 5-3	4011.2	2197.4
W 1-1	R 5-4	4531.4	2165.8
W 1-1	R 6-1	0.0	0.0
W 1-1	R 7-1	4090.5	2369.4
W 1-1	R 7-2	3015.6	1894.7
W 1-1	R 7-3	3748.7	2280.0
W 1-1	R 7-4	4290.1	2351.6
W 1-1	R 8-1	2839.7	440.5
W 1-1	R 8-2	2637.6	676.4
W 1-1	R 8-3	3087.5	-141.2
W 1-1	R 8-4	0.0	0.0
W 1-1	R 9-1	4135.5	2045.1
W 1-1	R 9-2	4340.1	1855.8
W 1-1	R 9-3	0.0	0.0
W 1-1	R10-1	6784.3	4098.6
W 1-1	R10-2	0.0	0.0
W 1-1	R10-3	6401.1	4063.5
W 1-1	R11-1	1528.6	225.1
W 1-1	R11-2	0.0	0.0
W 1-1	R11-3	1328.6	374.8

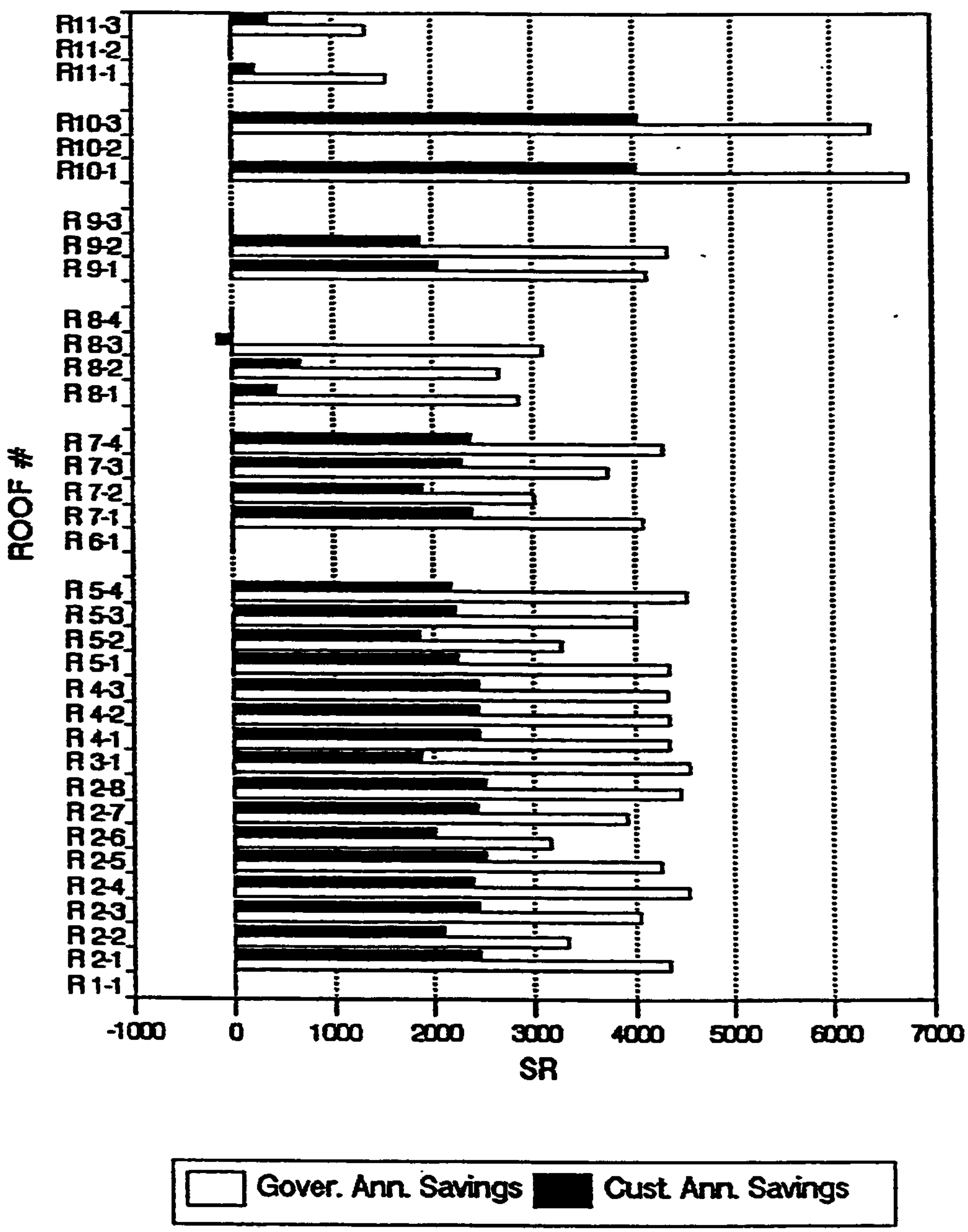


Figure 6.40: Jeddah - Annual savings (roofs).

6.1.3.3 Combined performance

Figure 6.41 shows the government and customer's annual savings for the combination case in Jeddah city. From this bar chart, it is clear that the combinations of W2-3 R2-1 (interior 75mm expanded polystyrene on a CMU wall and exterior 75mm extruded polystyrene on a reinforced concrete roof) and W5-3 R2-1 (exterior 75mm expanded polystyrene on a CMU wall and exterior 75mm extruded polystyrene on a reinforced concrete roof) give the highest annual savings for the customers. For the government, the combinations of W2-3 R2-4 (interior 75mm expanded polystyrene on a CMU wall and exterior 100mm extruded polystyrene on a reinforced concrete roof) and W5-3 R2-4 (exterior 75mm expanded polystyrene on a CMU wall and exterior 100mm extruded polystyrene on a reinforced concrete roof) will give the maximum annual savings.

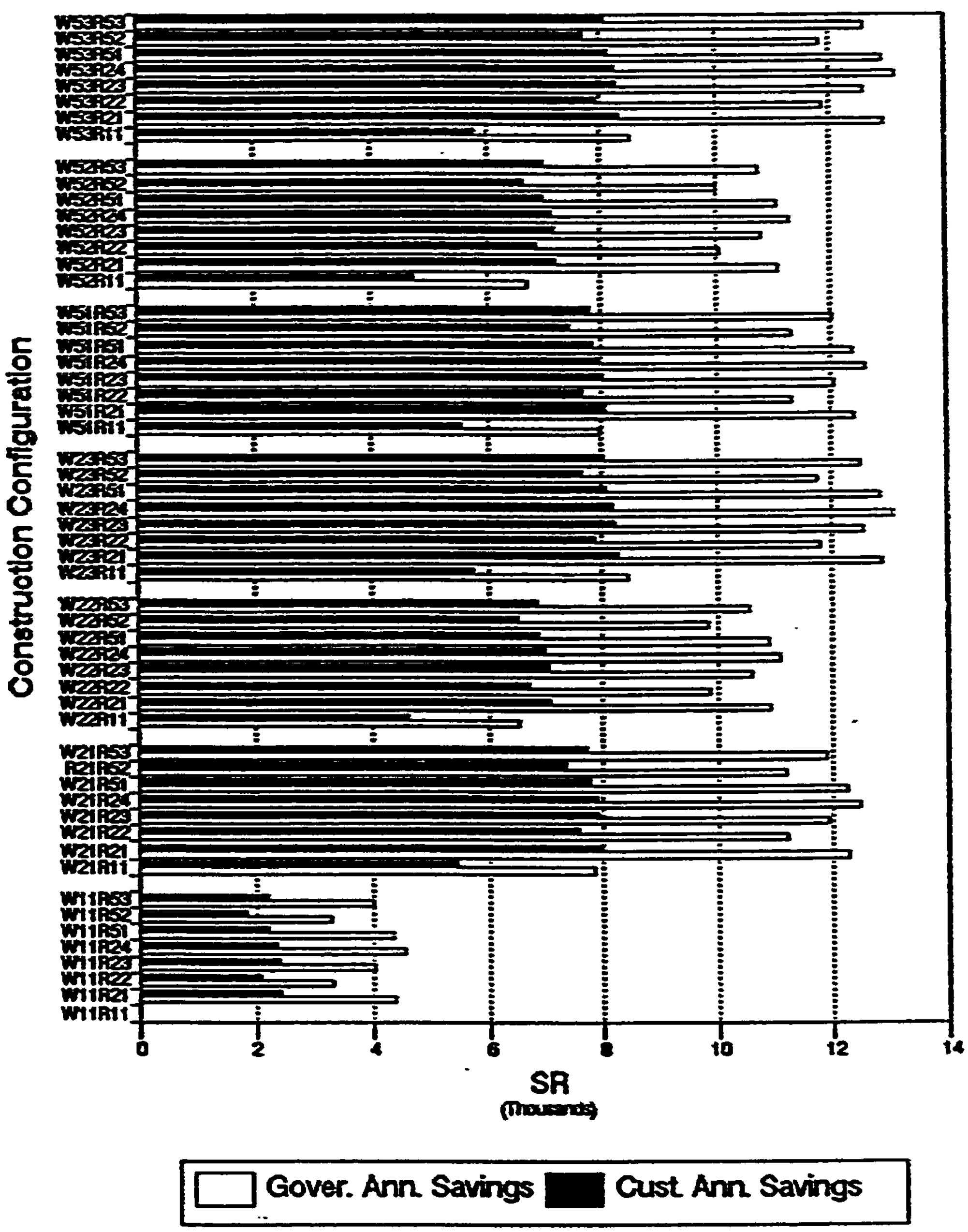


Figure 6.41: Jeddah - Annual savings (combinations).

6.1.3.4 Optimization graphs

Figures 6.42 through 6.45 illustrate the economic performance of each material among its group for both walls and roofs. From these figures, the following findings can be seen:

- Figure 6.42 shows that the expanded polystyrene board when used on the interior of the CMU wall will give the best economic performance, especially for thicknesses greater than 50mm. For thicknesses less than 50mm, the polyurethane board when used on the exterior will show the best performance.
- Figure 6.43 shows that among the rest of the wall groups (groups 2 to 5) in Jeddah city, the interior expanded polystyrene on the split-faced block wall will show the best economic performance.
- Figure 6.44 shows that among group 1 of the roofs in Jeddah, the expanded polystyrene when used on the exterior of a reinforced concrete roof will give the highest customer's annual savings.
- Figure 6.45 shows that the extruded polystyrene when used on the exterior of a precast hollow core roof will show the best economic performance among the roof's groups 2 to 6.

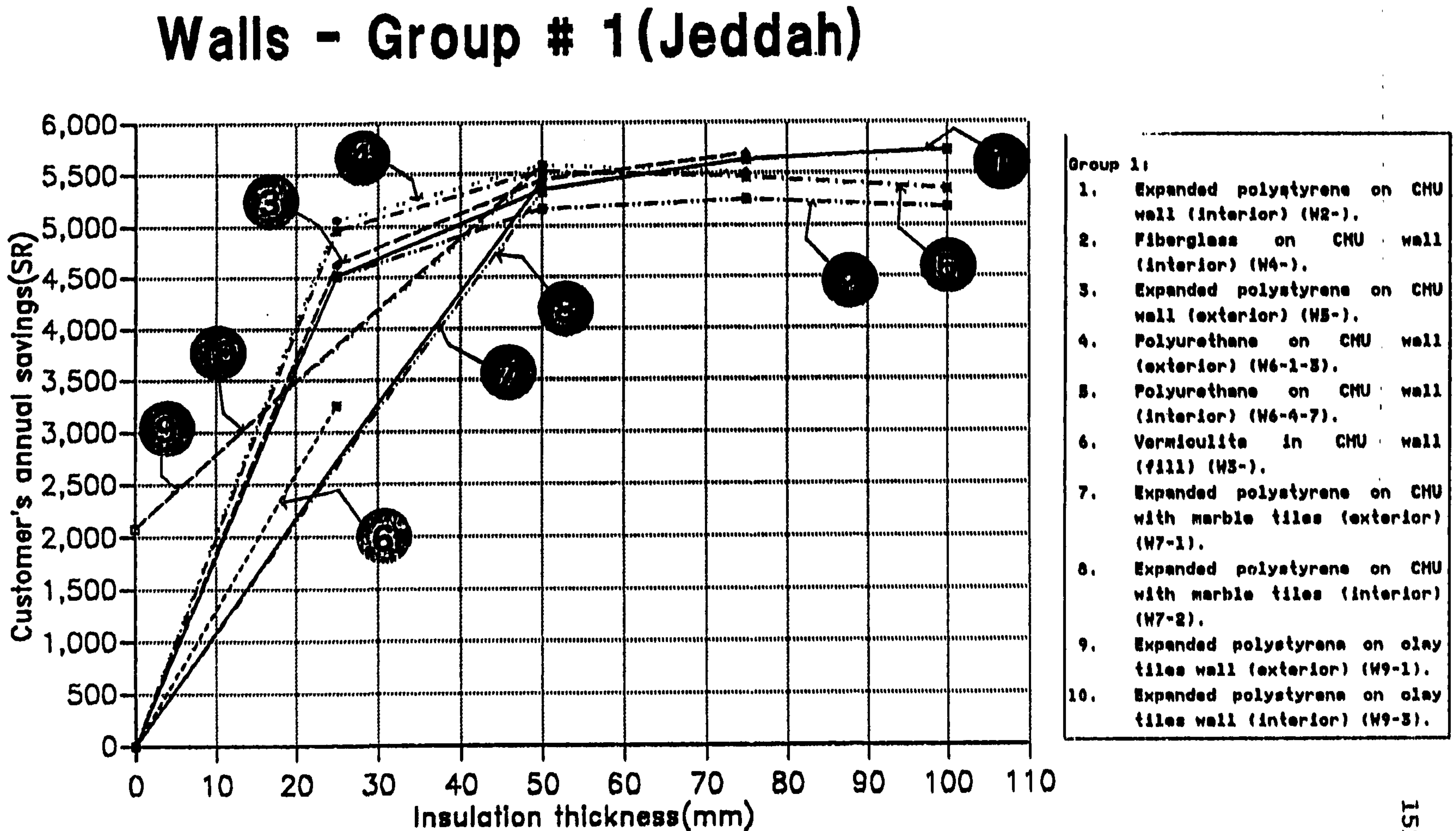


Figure 6.42: Jeddah - Walls # 1 (Economic performance).

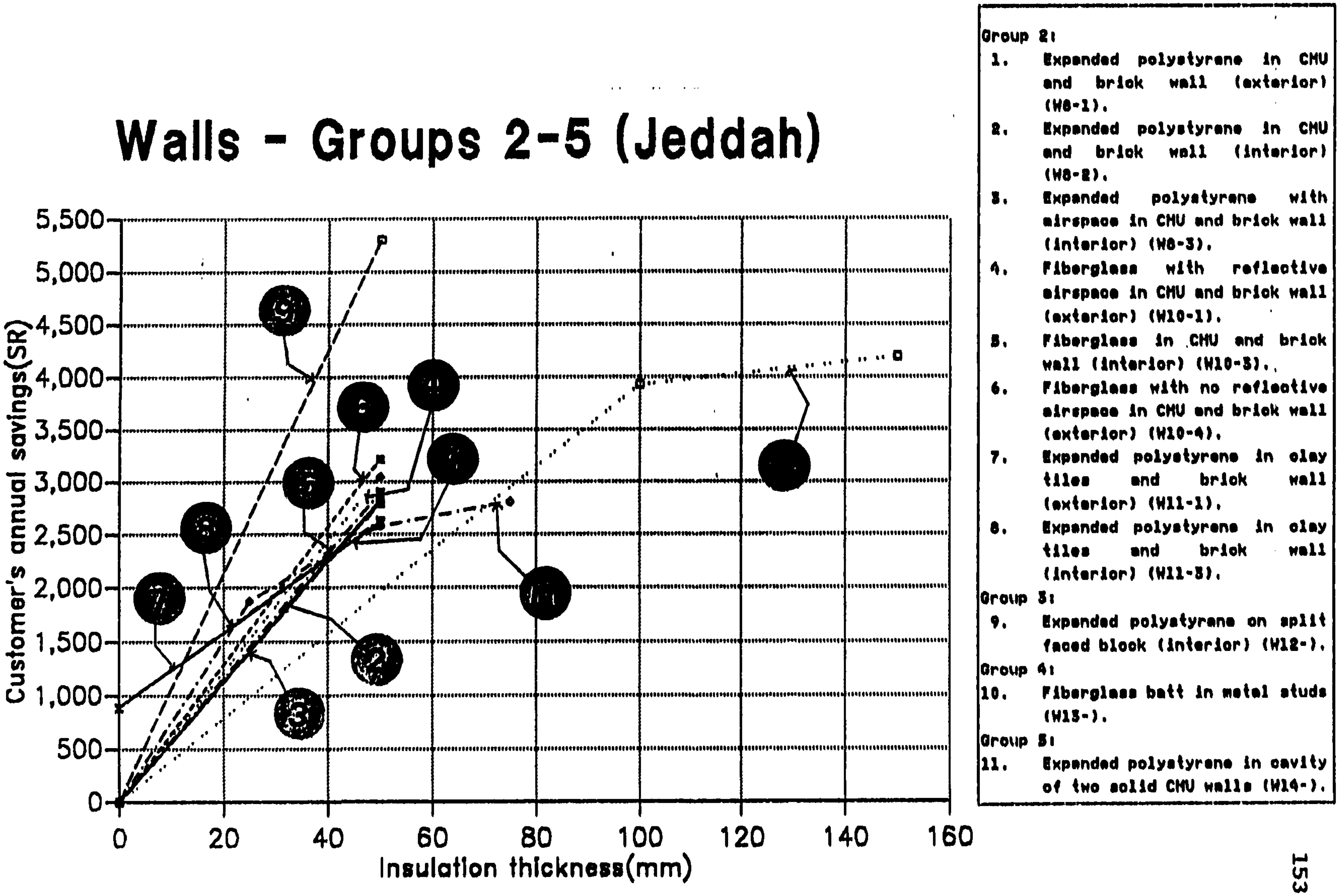


Figure 6.43: Jeddah - Walls # 2 - 5 (Economic performance). .

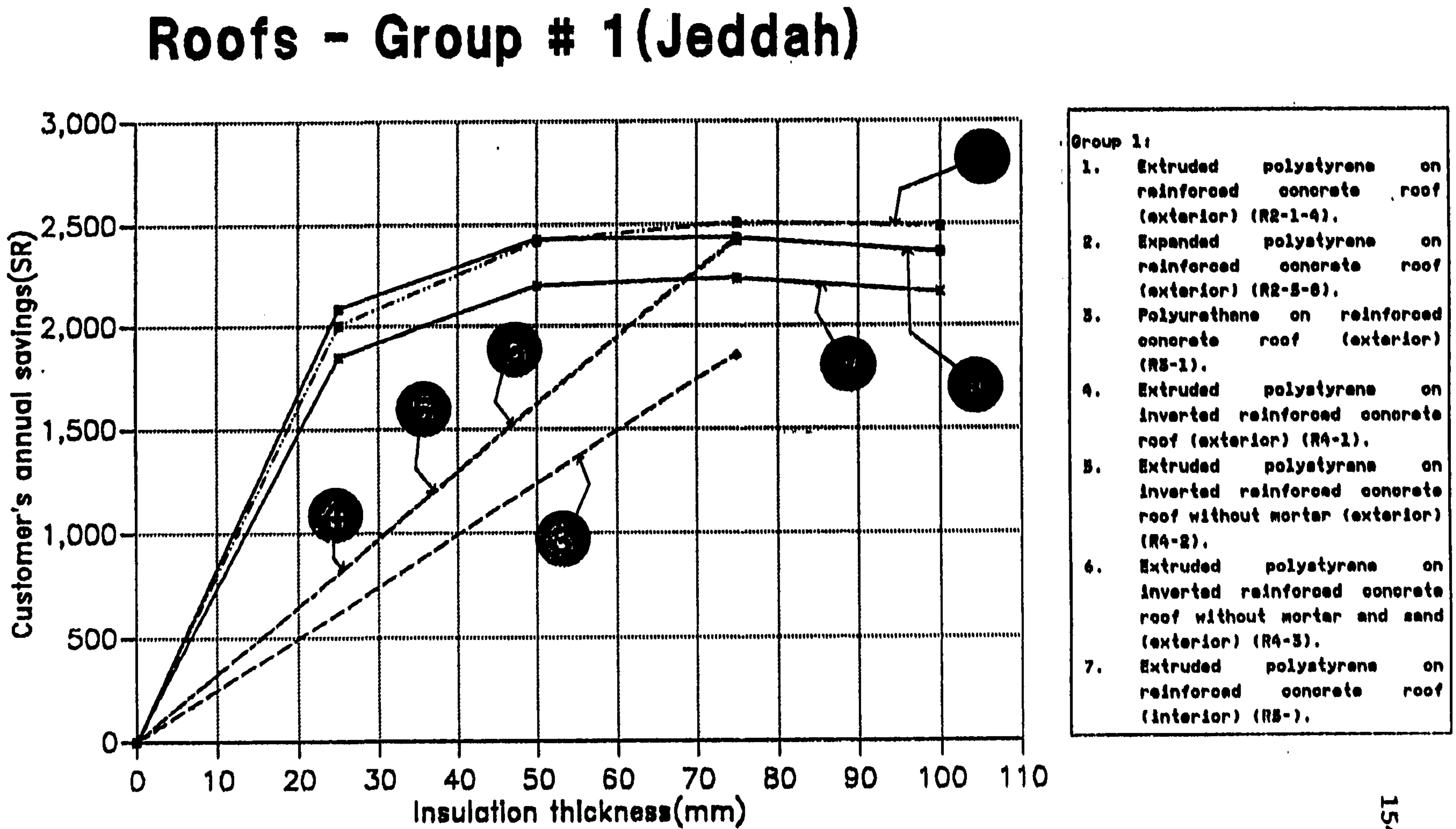


Figure 6.44: Jeddah - Roofs # 1 (Economic performance).

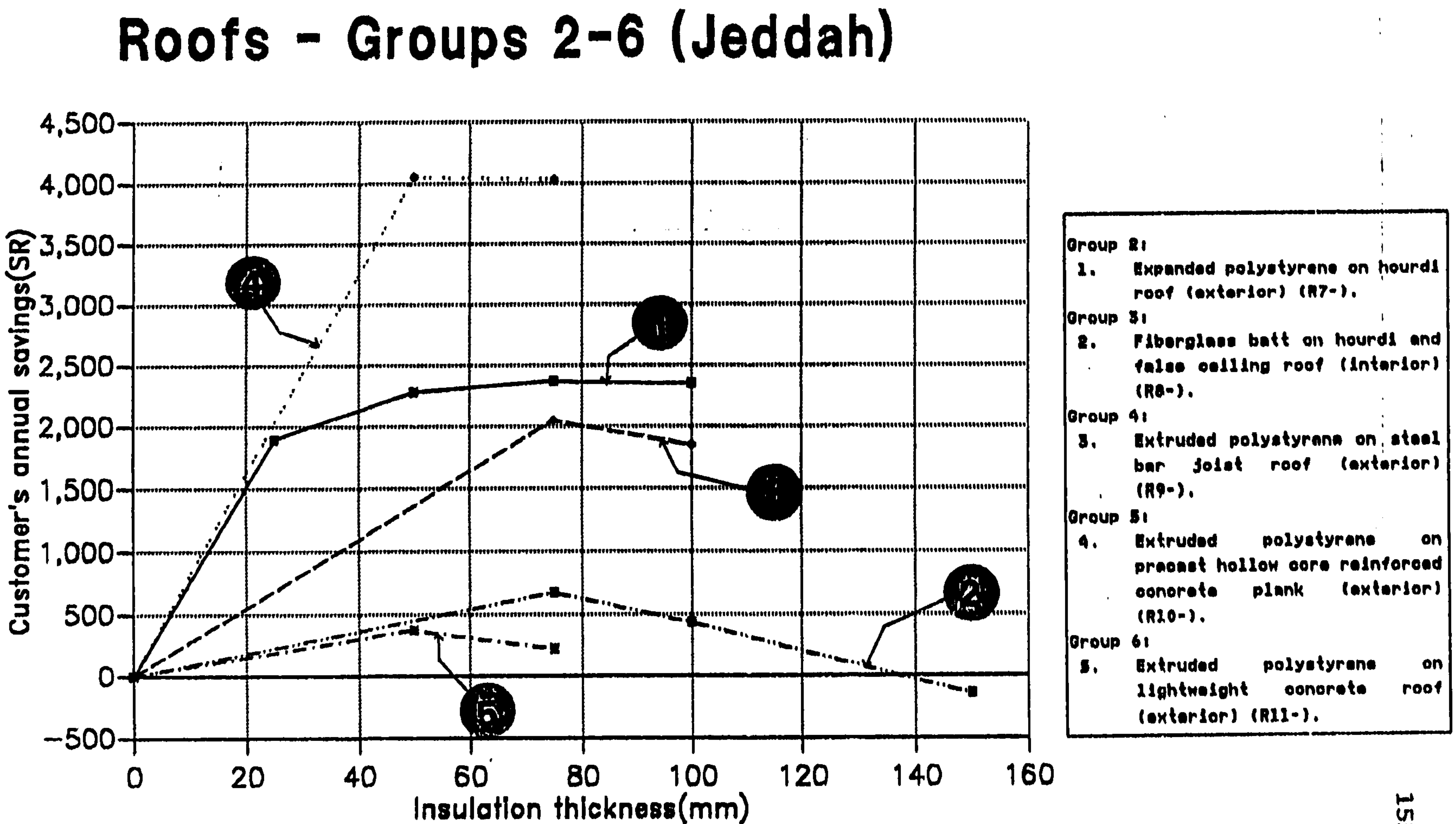


Figure 6.45: Jeddah - Roofs # 2 - 6 (Economic performance).

6.1.3.5 Wall and roof U-values (Customers)

Figures 6.46 through 6.49 represent the thermal performance of each variation versus the customer's annual savings within a group of walls or roofs. The extracted U-values from these figures are summarized in section 6.2.

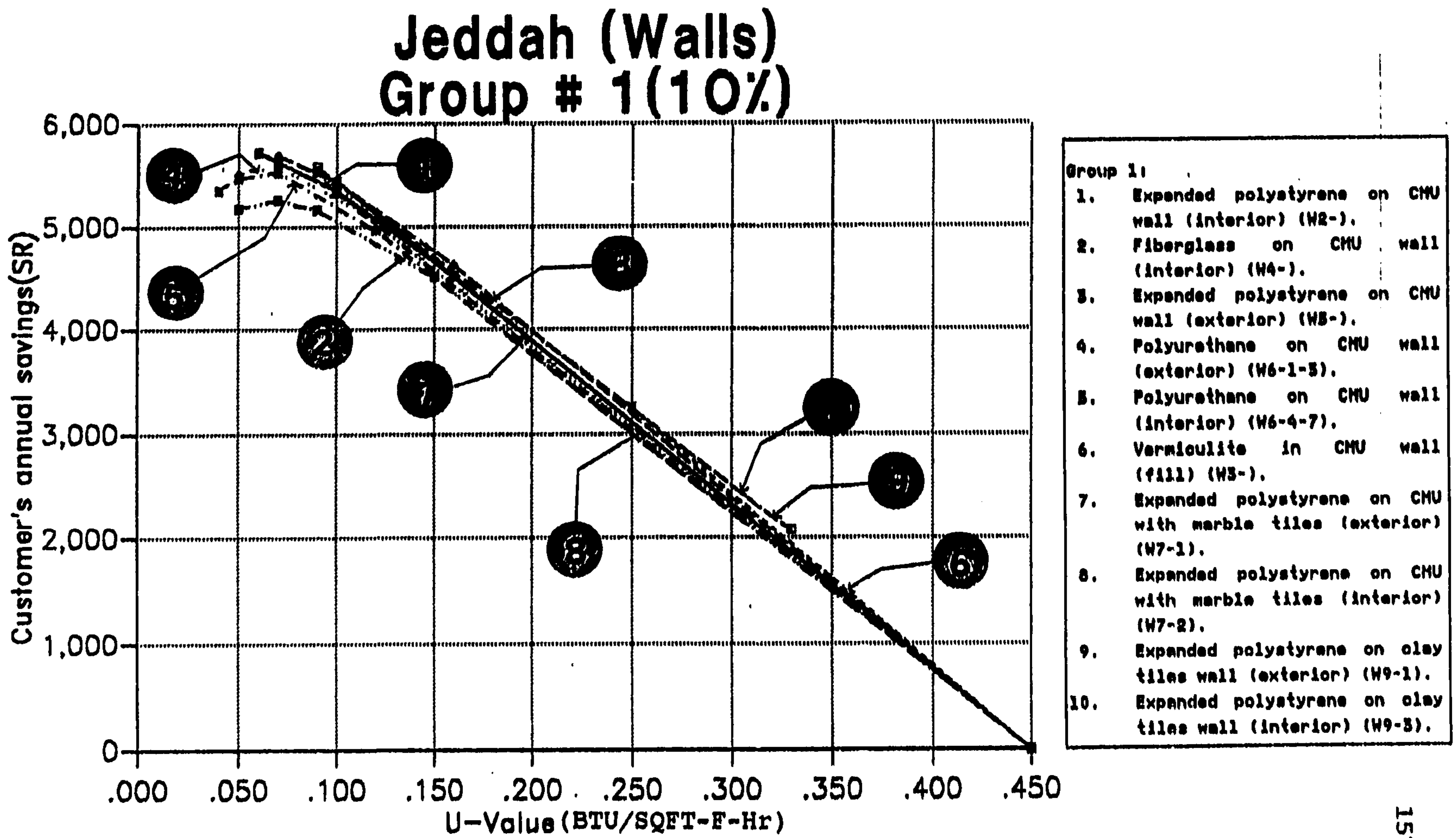
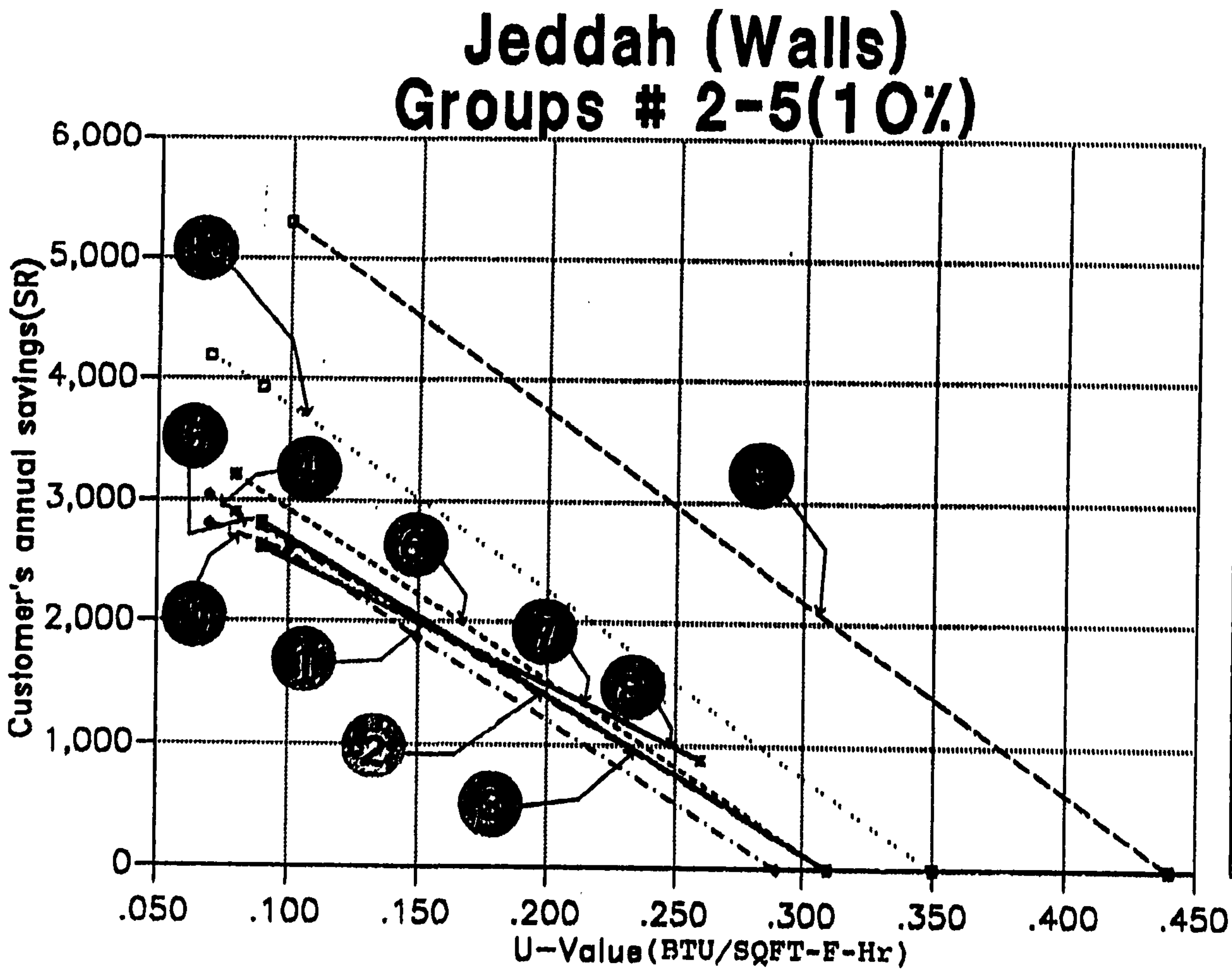


Figure 6.46: Jeddah - Walls # 1 (Thermal performance (customer)).



Group 2:

1. Expanded polystyrene in CMU and brick wall (exterior) (W8-1).
2. Expanded polystyrene in CMU and brick wall (interior) (W8-2).
3. Expanded polystyrene with airspace in CMU and brick wall (interior) (W8-3).
4. Fiberglass with reflective airspace in CMU and brick wall (exterior) (W10-1).
5. Fiberglass in CMU and brick wall (interior) (W10-3).
6. Fiberglass with no reflective airspace in CMU and brick wall (exterior) (W10-4).
7. Expanded polystyrene in clay tiles and brick wall (exterior) (W11-1).
8. Expanded polystyrene in clay tiles and brick wall (interior) (W11-3).

Group 3:

9. Expanded polystyrene on split faced block (interior) (W12-).

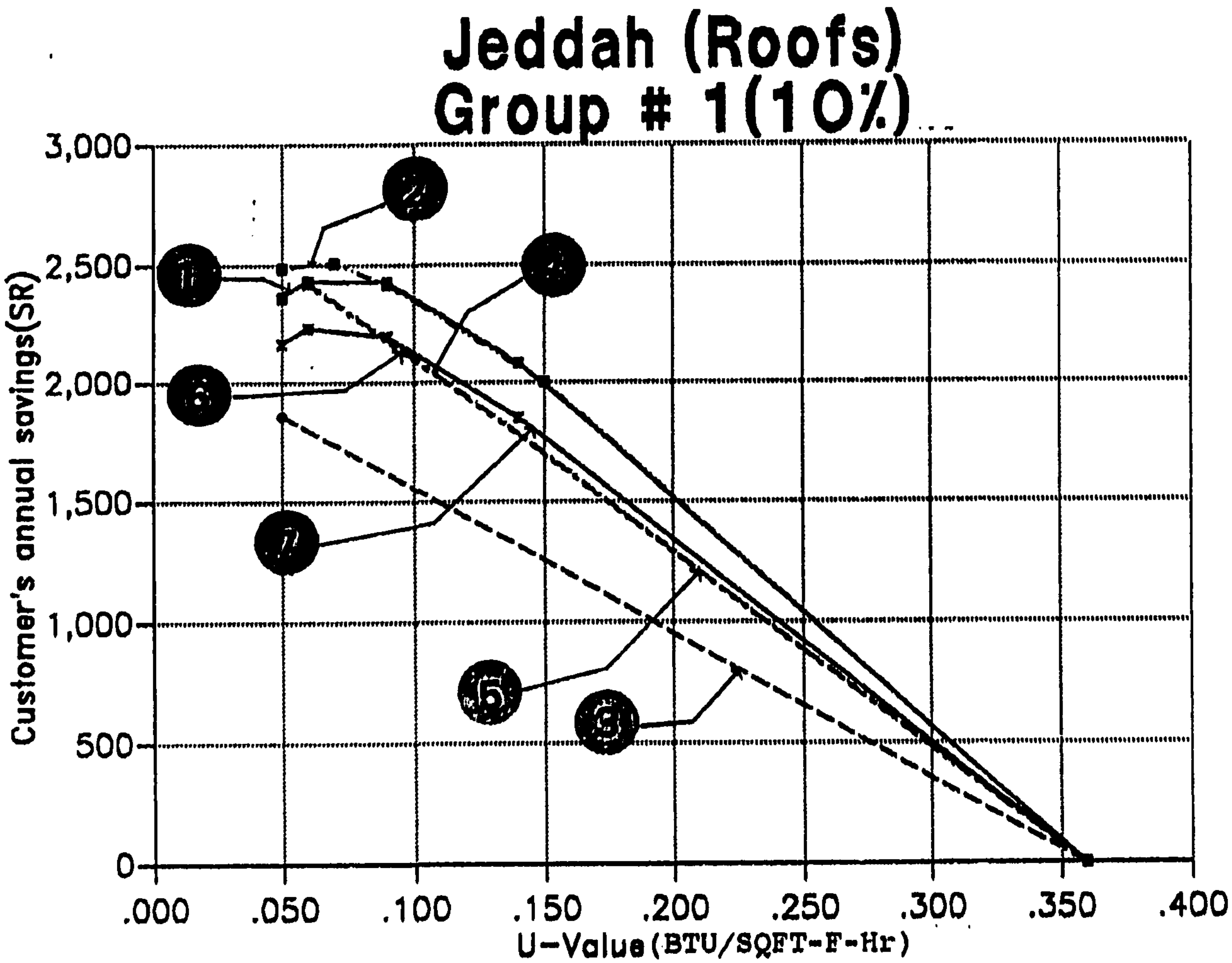
Group 4:

10. Fiberglass batt in metal studs (W13-).

Group 5:

11. Expanded polystyrene in cavity of two solid CMU walls (W14-).

Figure 6.47: Jeddah - Walls # 2-5 (Thermal performance (customer)).



Group 1:

1. Extruded polystyrene on reinforced concrete roof (exterior) (R2-1-4).
2. Expanded polystyrene on reinforced concrete roof (exterior) (R2-5-8).
3. Polyurethane on reinforced concrete roof (exterior) (R3-1).
4. Extruded polystyrene on inverted reinforced concrete roof (exterior) (R4-1).
5. Extruded polystyrene on inverted reinforced concrete roof without morter (exterior) (R4-2).
6. Extruded polystyrene on inverted reinforced concrete roof without morter and sand (exterior) (R4-3).
7. Extruded polystyrene on reinforced concrete roof (interior) (R5-).

Figure 6.48: Jeddah - Roofs # 1 (Thermal performance (customer)).

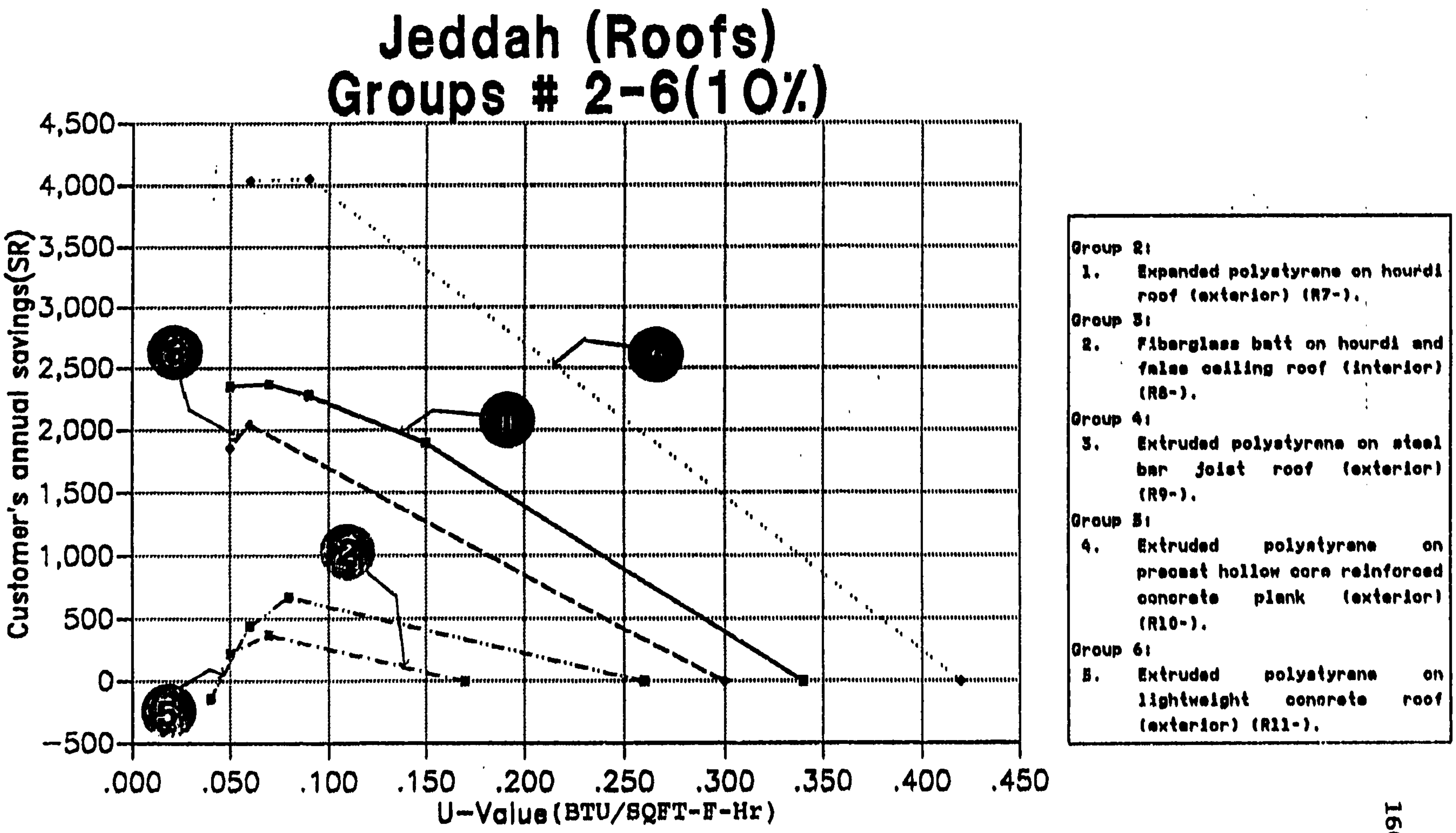


Figure 6.49: Jeddah - Roofs # 2-6 (Thermal performance (customer)).

6.1.3.6 Wall and roof U-values (Government)

Figures 6.50 through 6.53 represent the thermal performance of each variation versus government's annual savings within a group of walls or roofs. The extracted U-values are summarized in section 6.2.

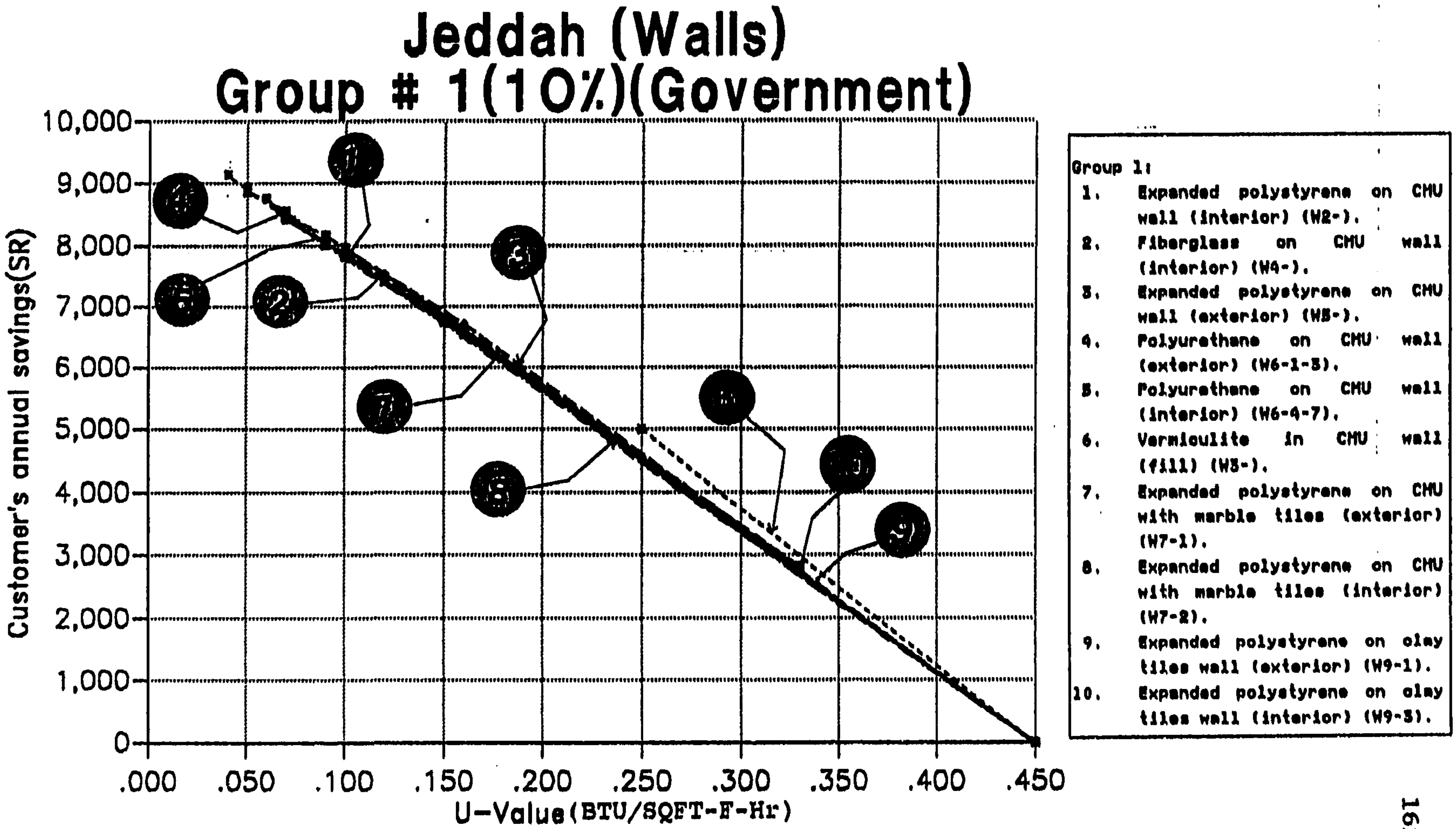
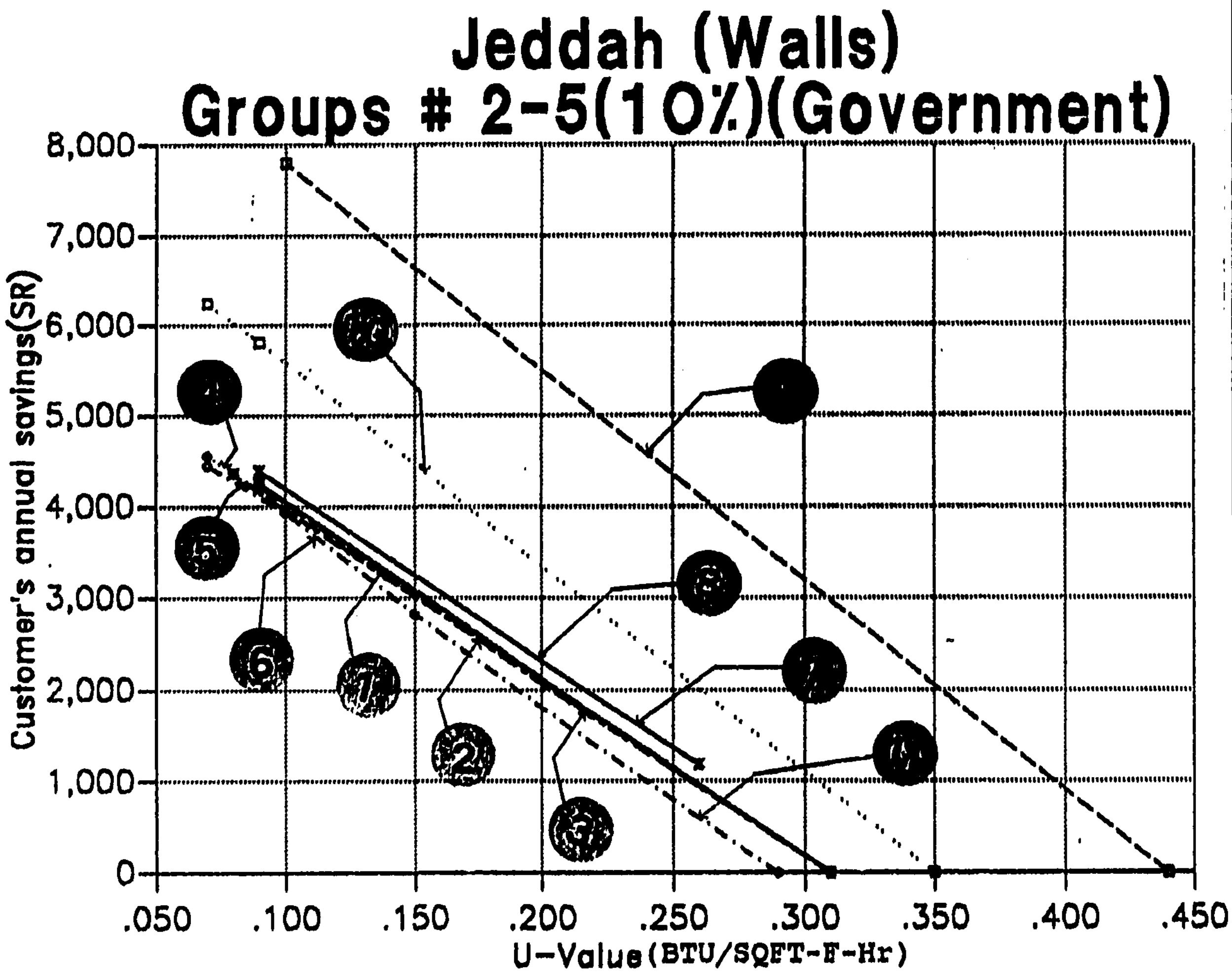


Figure 6.50: Jeddah - Walls # 1 (Thermal performance (government)).



Group 2:

1. Expanded polystyrene in CMU and brick wall (exterior) (W8-1).
2. Expanded polystyrene in CMU and brick wall (interior) (W8-2).
3. Expanded polystyrene with airspace in CMU and brick wall (interior) (W8-3).
4. Fiberglass with reflective airspace in CMU and brick wall (exterior) (W10-1).
5. Fiberglass in CMU and brick wall (interior) (W10-3).
6. Fiberglass with no reflective airspace in CMU and brick wall (exterior) (W10-4).
7. Expanded polystyrene in clay tiles and brick wall (exterior) (W11-1).
8. Expanded polystyrene in clay tiles and brick wall (interior) (W11-3).

Group 3:

9. Expanded polystyrene on split faced block (interior) (W12-).

Group 4:

10. Fiberglass batt in metal studs (W13-).

Group 5:

11. Expanded polystyrene in cavity of two solid CMU walls (W14-).

Figure 6.51: Jeddah - Walls # 2-5 (Thermal performance (government)).

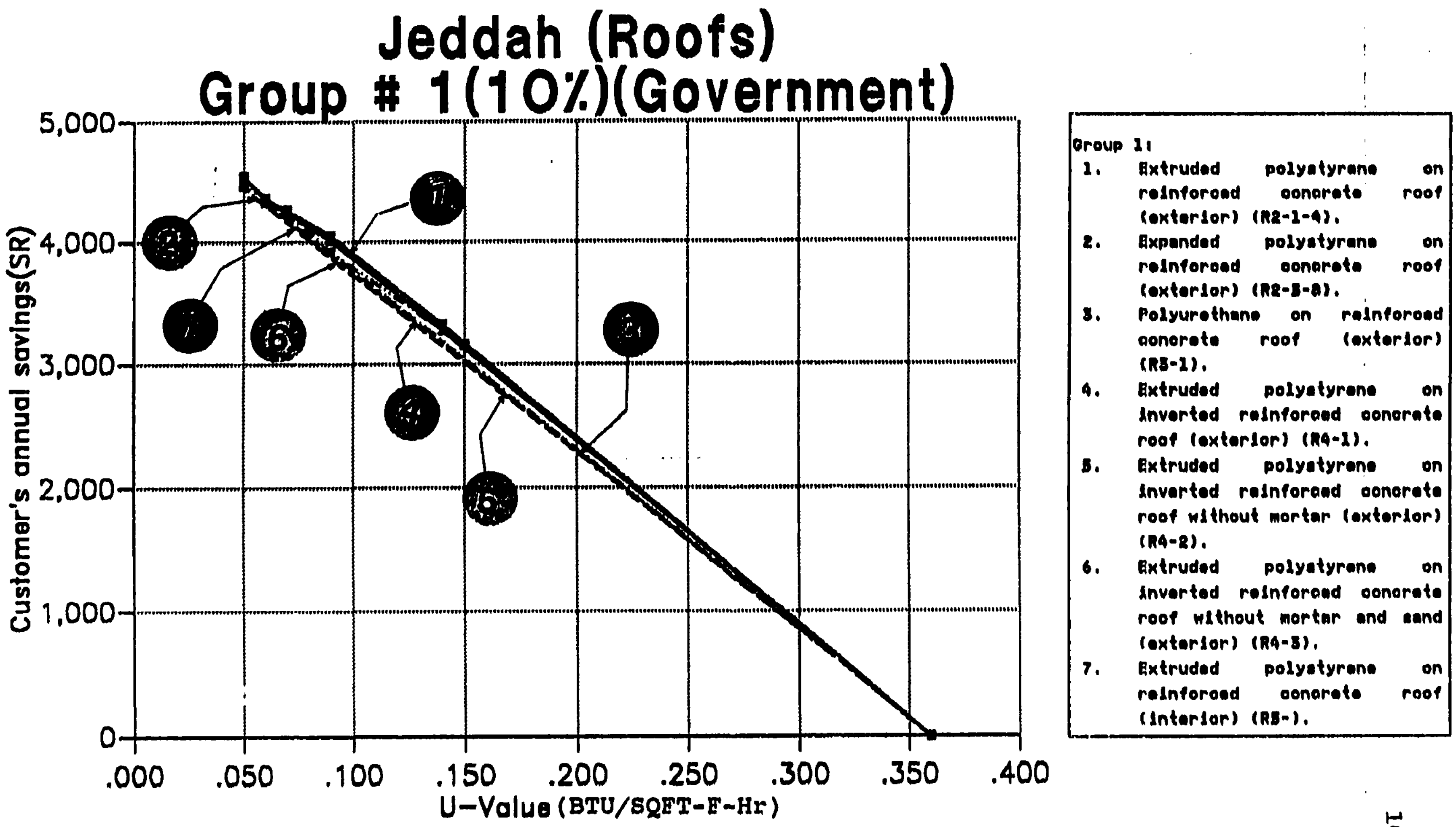


Figure 6.52: Jeddah - Roofs # 1 (Thermal performance (government)).

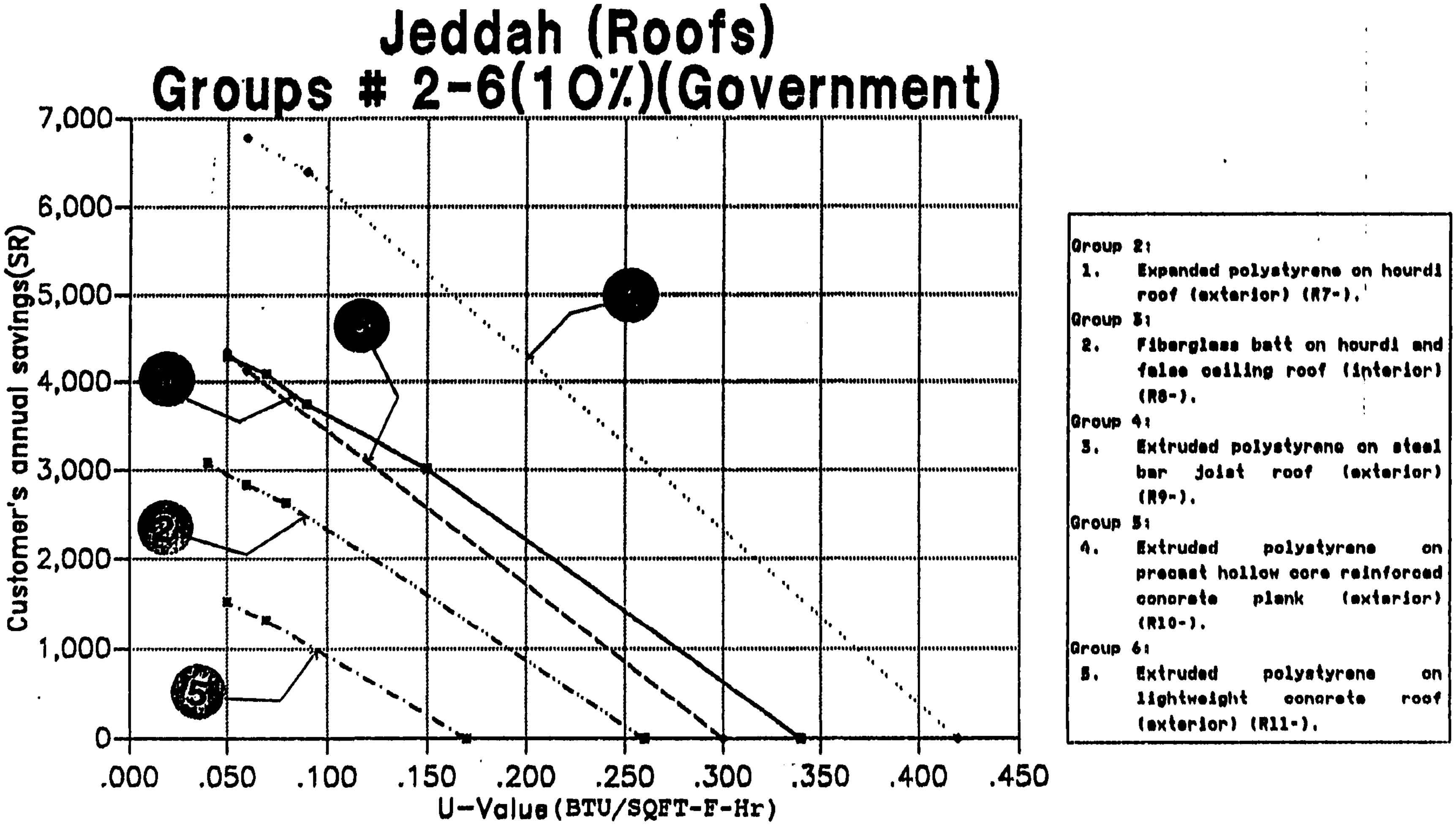


Figure 6.53: Jeddah - Roofs # 2-6 (Thermal performance (government)).

6.1.4 Khamis Mushait city

6.1.4.1 Economic performance of walls

Table 6.8 lists the annual savings for the government and the customers for wall configurations in Khamis Mushait city. These results are presented graphically in Figure 6.54.

Figure 6.54 shows that wall W9-1 (exterior 50mm expanded polystyrene board) gives the best savings among group 1 for the customers, while wall W6-7 (interior 100mm polyurethane) will give the maximum savings for the government.

In group 2, wall W10-4 (exterior 50mm fiberglass with a non reflective airspace) gives the best savings among the group for the customers. Wall W10-1 (exterior 50mm fiberglass with reflective airspace) gives the highest savings for the government.

In group 3, wall W12-1 (interior 50mm expanded polystyrene) gives the best savings for both government and customers.

In group 4, wall W13-2 (150mm fiberglass batt) gives the best saving among its group for both government and customers.

Finally, in group 5, wall W14-4 (cavity 75mm expanded polystyrene) gives the highest savings in its group for both government and customers.

Table 6.8: Khamis - Annual savings (walls).

WALL	ROOF	GOVERN. ANNUAL SAVINGS	CUSTOM. ANNUAL SAVINGS
W 1-1	R 1-1	0.0	0.0
W 2-1	R 1-1	4915.6	3850.6
W 2-2	R 1-1	4156.8	3325.9
W 2-3	R 1-1	5234.5	3978.8
W 2-4	R 1-1	5411.4	3979.2
W 3-1	R 1-1	3369.8	2453.1
W 4-1	R 1-1	5008.6	3615.1
W 4-2	R 1-1	4282.3	3283.9
W 4-3	R 1-1	5306.5	3573.4
W 4-4	R 1-1	5474.5	3404.4
W 5-1	R 1-1	5055.9	3926.5
W 5-2	R 1-1	4373.8	3440.5
W 5-3	R 1-1	5333.9	4030.7
W 6-1	R 1-1	5353.4	3903.9
W 6-2	R 1-1	4830.8	3664.7
W 6-3	R 1-1	5564.5	3733.9
W 6-4	R 1-1	5194.9	3749.6
W 6-5	R 1-1	4598.0	3466.2
W 6-6	R 1-1	5494.9	3692.5
W 6-7	R 1-1	5629.4	3511.1
W 7-1	R 1-1	5057.3	3926.2
W 7-2	R 1-1	4887.6	3836.4
W 9-1	R 1-1	5198.7	4040.5
W 9-2	R 1-1	1957.6	1661.9
W 9-3	R 1-1	5114.0	3996.6
W 8-1	R 1-1	2237.6	1741.2
W 8-2	R 1-1	2198.1	1713.8
W 8-3	R 1-1	2214.0	1730.8
W10-1	R 1-1	2571.5	1873.2
W10-2	R 1-1	0.0	0.0
W10-3	R 1-1	2262.7	1775.4
W10-4	R 1-1	2262.7	2090.2
W11-1	R 1-1	2511.0	1491.7
W11-2	R 1-1	729.2	655.2
W11-3	R 1-1	2281.9	1469.7
W12-1	R 1-1	4871.2	3810.7
W12-2	R 1-1	0.0	0.0
W13-1	R 1-1	3717.2	3022.9
W13-2	R 1-1	3963.0	3187.8
W13-3	R 1-1	0.0	0.0
W14-1	R 1-1	2137.6	1599.5
W14-2	R 1-1	0.0	0.0
W14-3	R 1-1	1583.3	1224.0
W14-4	R 1-1	2377.9	1674.9

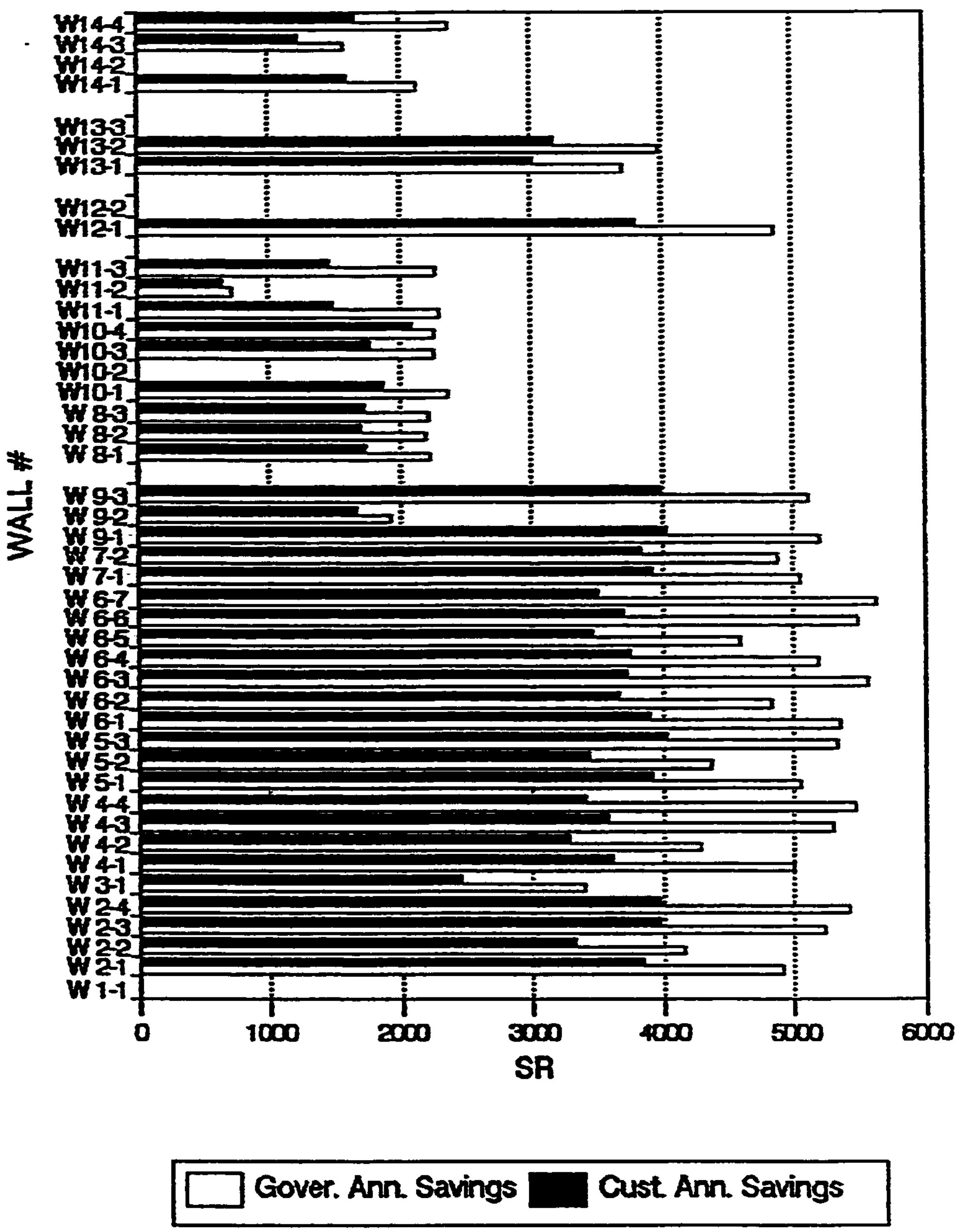


Figure 6.54: Khamis - Annual savings (walls).

6.1.4.2 Economic performance of roofs

Table 6.9 shows the economic performance of roofs in Khamis Mushait city. This is illustrated graphically in Figure 6.55.

This figure shows that for group 1, roof R2-7 (exterior 50mm expanded polystyrene) gives the maximum customer's annual savings, while roofs R2-4 (exterior 100mm extruded polystyrene) and R3-1 (exterior 75mm polyurethane) give the maximum government's annual savings.

In group 2, roof R7-3 (exterior 50mm expanded polystyrene) gives the highest savings in this group for the customers, while roof R7-4 (exterior 100mm expanded polystyrene) gives the maximum annual savings for the government.

In group 3, all roofs show losses for the customers, but for the government, roof R8-3 (interior 150mm fiberglass batt) gives the best government's annual saving.

In group 4, roof R9-1 (exterior 75mm extruded polystyrene) gives the maximum annual savings for the customers, while roof R9-2 (exterior 100mm extruded polystyrene) gives the highest annual savings for the government.

In group 5, roof R10-3 (exterior 50mm extruded polystyrene) gives the highest annual savings for the customer's, while roof R10-1 (exterior 75mm extruded polystyrene) gives the highest annual savings for the government.

In the last group, all roofs show losses for the customers, while for the government roof R11-1 (exterior 75mm extruded polystyrene) gives the highest annual savings.

Table 6.9: Khamis - Annual savings (roofs).

WALL	ROOF	GOVERN. ANNUAL SAVINGS	CUSTOM. ANNUAL SAVINGS
W 1-1	R 1-1	0.0	0.0
W 1-1	R 2-1	2284.3	1347.4
W 1-1	R 2-2	1791.0	1270.1
W 1-1	R 2-3	2150.7	1404.0
W 1-1	R 2-4	2370.5	1218.9
W 1-1	R 2-5	2233.9	1430.9
W 1-1	R 2-6	1711.4	1232.9
W 1-1	R 2-7	2075.5	1441.2
W 1-1	R 2-8	2328.4	1357.2
W 1-1	R 3-1	2375.5	712.4
W 1-1	R 4-1	2283.9	1347.1
W 1-1	R 4-2	2273.6	1336.9
W 1-1	R 4-3	2258.3	1323.1
W 1-1	R 5-1	2257.3	1151.8
W 1-1	R 5-2	1744.0	1076.3
W 1-1	R 5-3	2108.7	1220.5
W 1-1	R 5-4	2547.6	1022.6
W 1-1	R 6-1	0.0	0.0
W 1-1	R 7-1	2199.2	1357.4
W 1-1	R 7-2	1683.3	1172.2
W 1-1	R 7-3	2042.6	1371.4
W 1-1	R 7-4	2293.2	1282.2
W 1-1	R 8-1	1446.6	-299.8
W 1-1	R 8-2	1347.7	-8.0
W 1-1	R 8-3	1560.1	-969.4
W 1-1	R 8-4	0.0	0.0
W 1-1	R 9-1	2786.5	1860.3
W 1-1	R 9-2	2945.0	1682.5
W 1-1	R 9-3	0.0	0.0
W 1-1	R10-1	4635.7	3018.3
W 1-1	R10-2	0.0	0.0
W 1-1	R10-3	4428.3	3125.2
W 1-1	R11-1	645.0	-271.0
W 1-1	R11-2	0.0	0.0
W 1-1	R11-3	558.6	-61.6

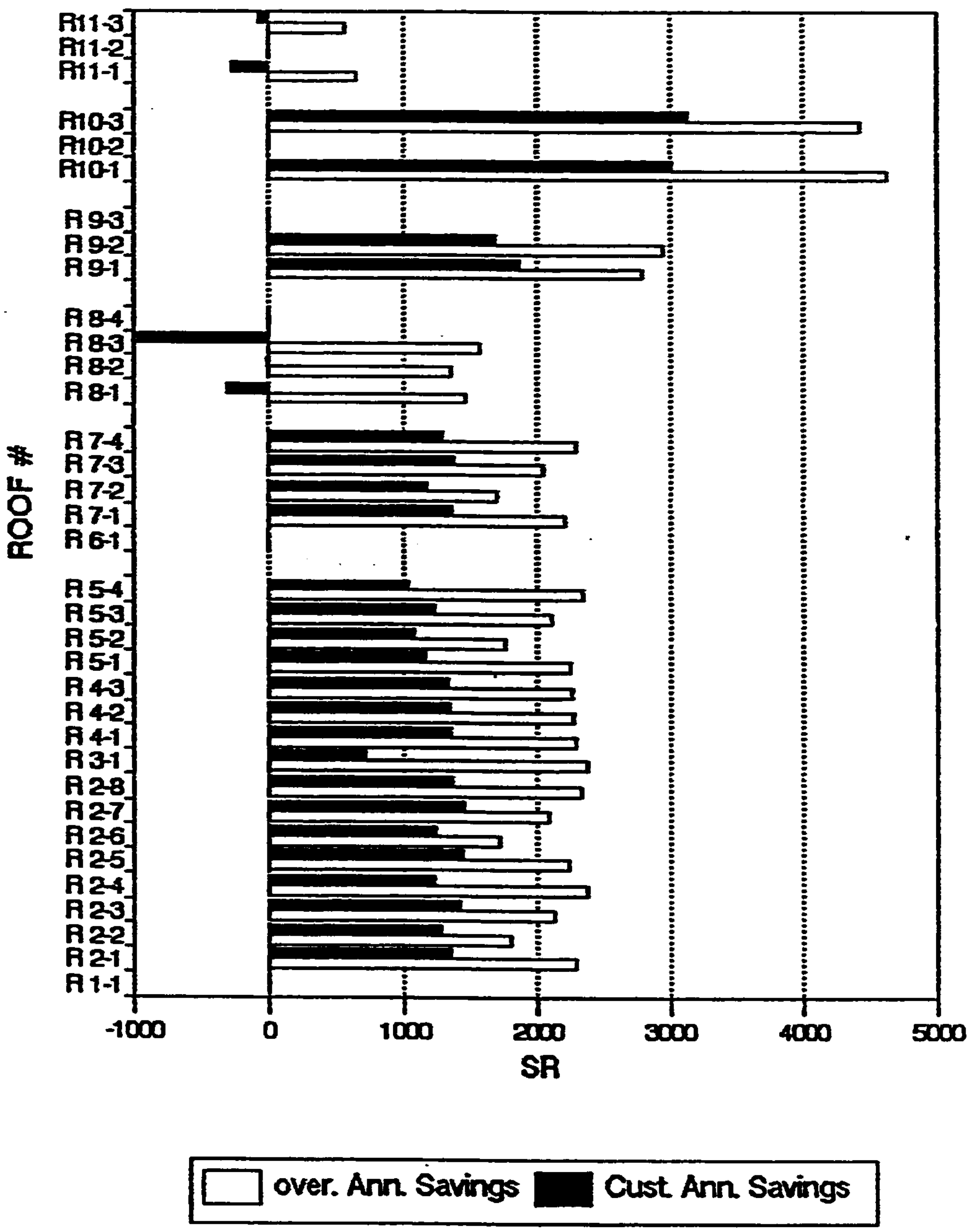


Figure 6.55: Khamis - Annual savings (roofs).

6.1.4.3 Combined performance

Figure 6.56 shows the government's and the customer's annual savings when insulating both walls and roofs simultaneously (combination) in Khamis Mushait city. From this bar chart, it is clear that the combination of W5-3 R2-3 (exterior 75mm expanded polystyrene on a CMU wall and exterior 50mm extruded polystyrene on a reinforced concrete roof) gives the highest annual savings for the customers. For the government, the combinations of W2-3 R2-4 (interior 75mm expanded polystyrene on a CMU wall and exterior 100mm extruded polystyrene on a reinforced concrete roof) and W5-3 R2-4 (exterior 75mm expanded polystyrene on a CMU wall and exterior 100mm extruded polystyrene on a reinforced concrete roof) will give the highest annual savings.

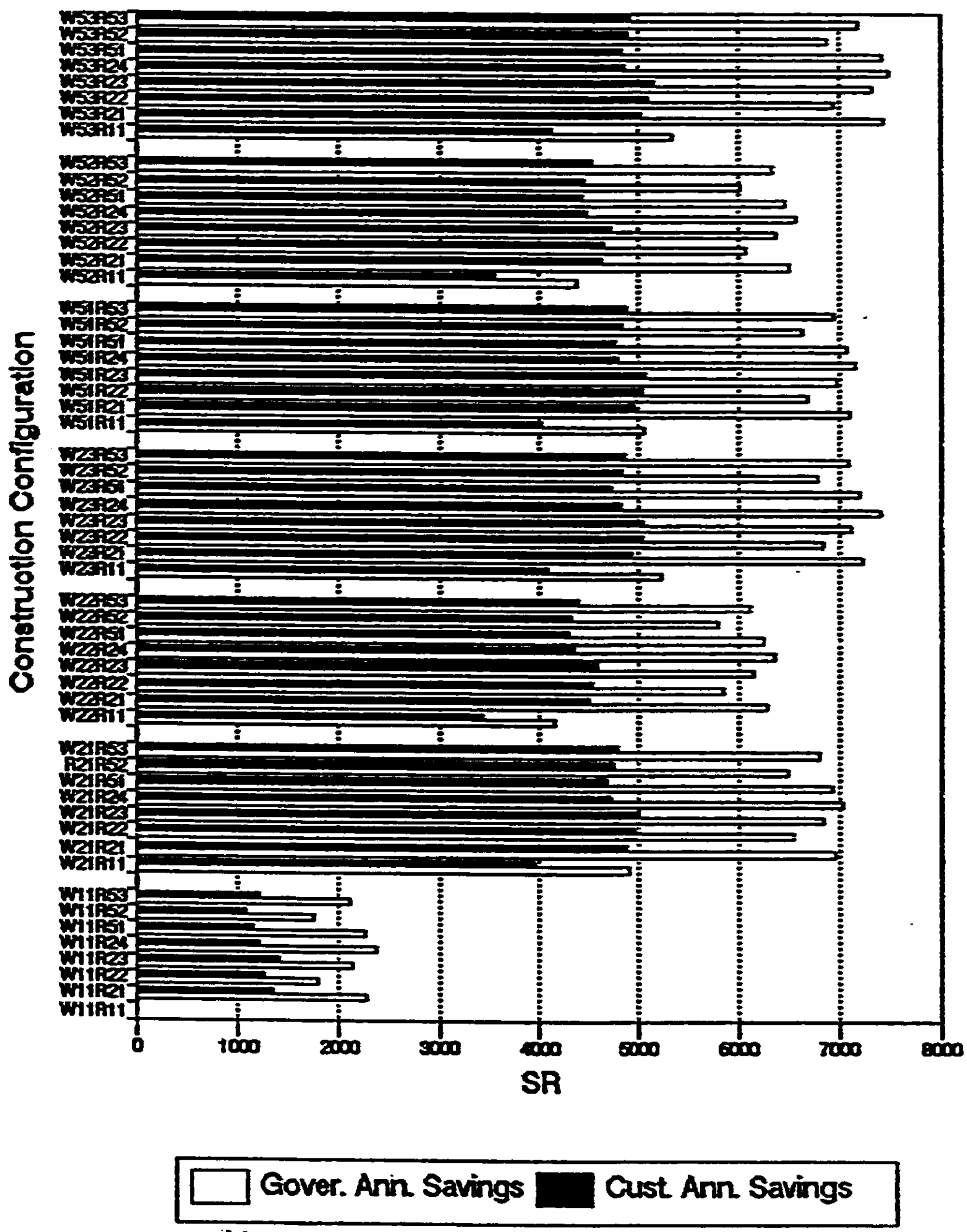


Figure 6.56: Khamis - Annual savings (combinations).

6.1.4.4 Optimization graphs

Figures 6.57 through 6.60 illustrate the economic performance of each material among its group for both walls and roofs. From these figures, the following can be seen:

- Figure 6.57 shows that the expanded polystyrene board when used on the interior of the CMU wall will give the best economic performance, especially for thicknesses greater than 50mm. For thicknesses less than 50mm, the polyurethane board when used on the exterior will show the best performance.
- Figure 6.58 shows that among the rest of the walls groups (groups 2 to 5) in Khamis city, the interior expanded polystyrene on the split faced block wall will show the best economic performance.
- Figure 6.59 shows that among group 1 of the roofs in Khamis, the expanded polystyrene when used on the exterior of a reinforced concrete roof will give the highest customer's annual savings.
- Figure 6.60 shows that the extruded polystyrene when used on the exterior of a precast hollow core roof will show the best economic performance among the roof's groups 2 to 6.

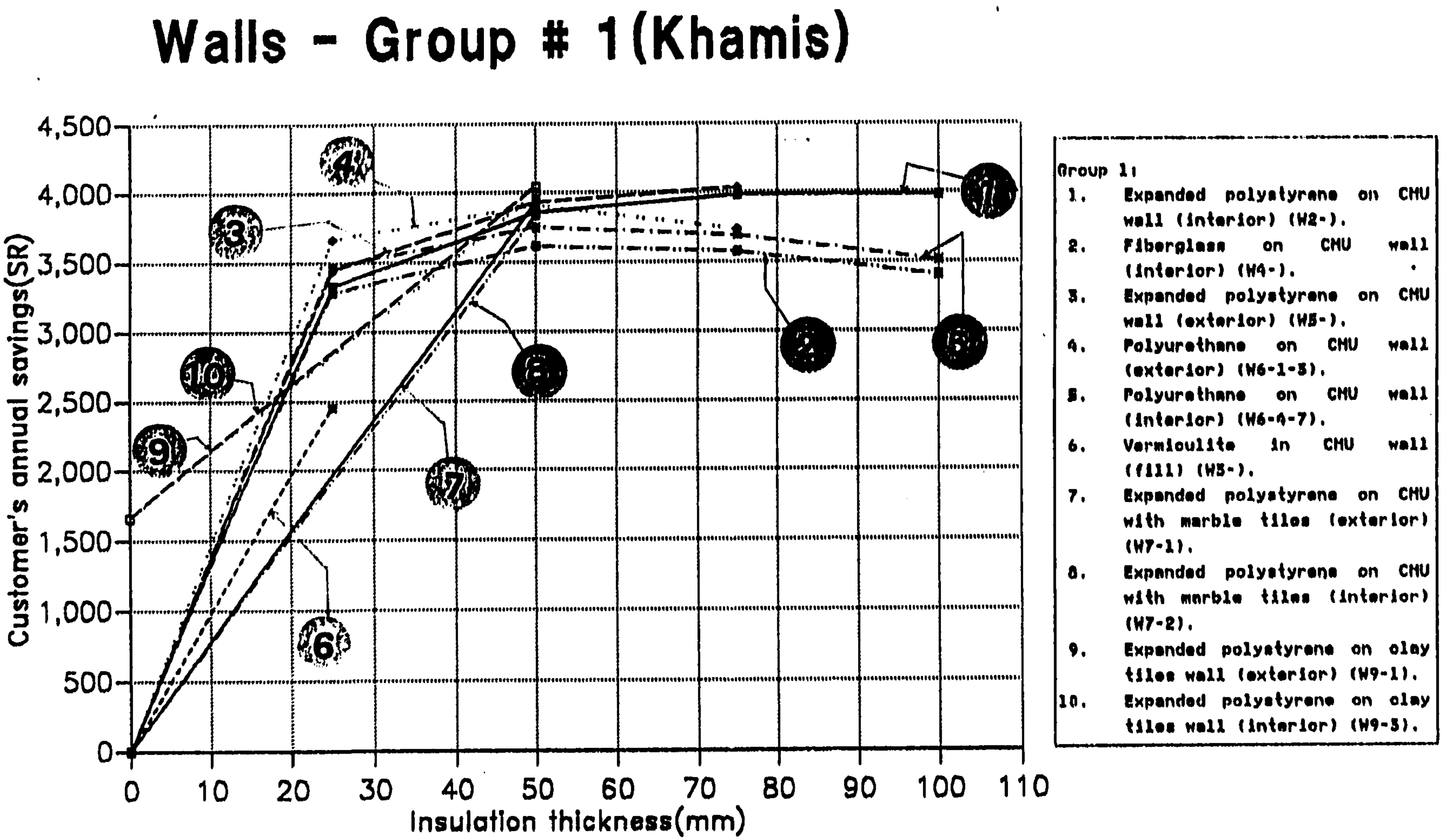
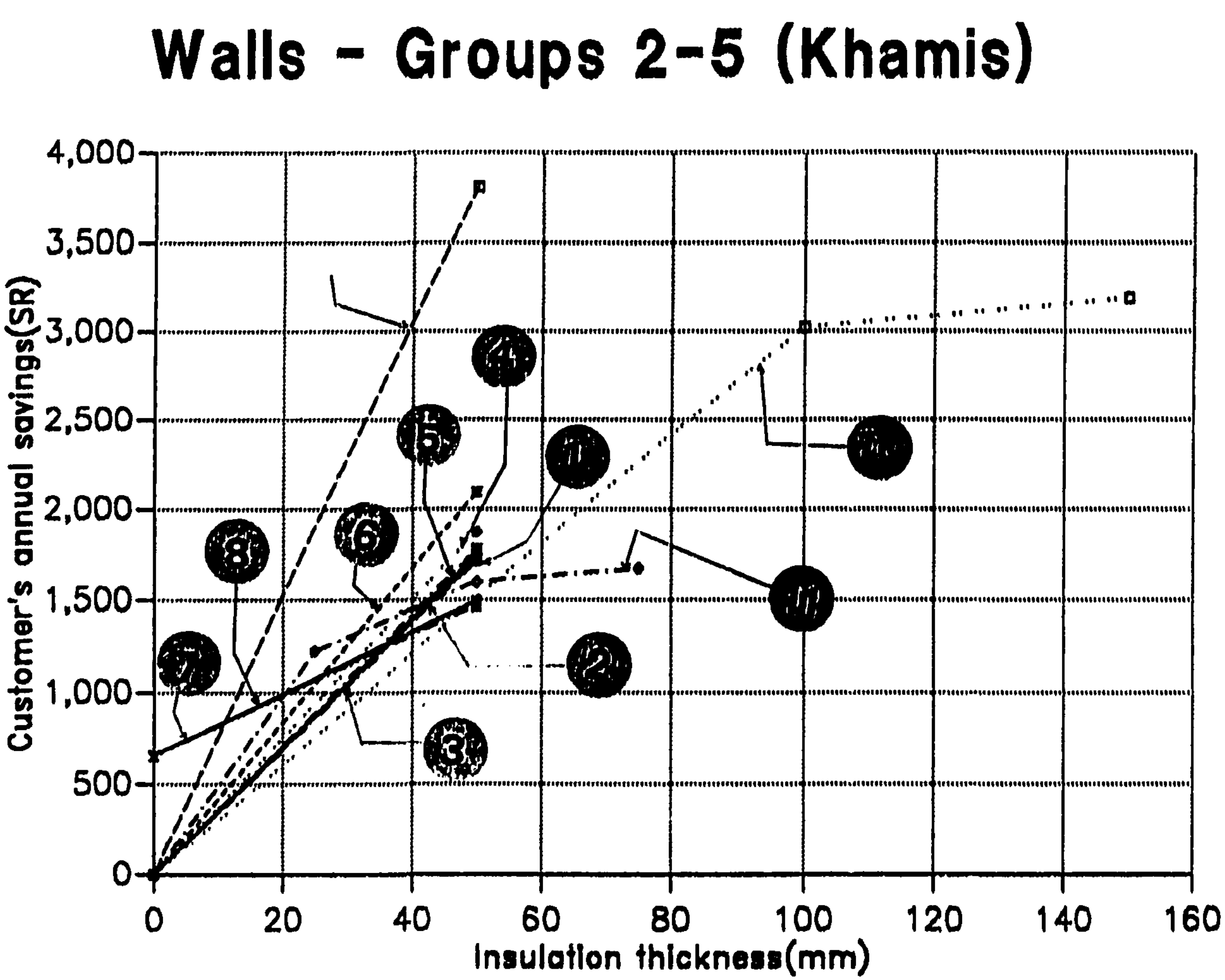


Figure 6.57: Khamis - Walls # 1 (Economic performance).



Group 2:

1. Expanded polystyrene in CMU and brick wall (exterior) (W8-1).
2. Expanded polystyrene in CMU and brick wall (interior) (W8-2).
3. Expanded polystyrene with airspace in CMU and brick wall (interior) (W8-3).
4. Fiberglass with reflective airspace in CMU and brick wall (exterior) (W10-1).
5. Fiberglass in CMU and brick wall (interior) (W10-3).
6. Fiberglass with no reflective airspace in CMU and brick wall (exterior) (W10-4).
7. Expanded polystyrene in clay tiles and brick wall (exterior) (W11-1).
8. Expanded polystyrene in clay tiles and brick wall (interior) (W11-3).

Group 3:

9. Expanded polystyrene on split faced block (interior) (W12-).

Group 4:

10. Fiberglass batt in metal studs (W13-).

Group 5:

11. Expanded polystyrene in cavity of two solid CMU walls (W14-).

Figure 6.58: Khamis - Walls # 2 - 5 (Economic performance).

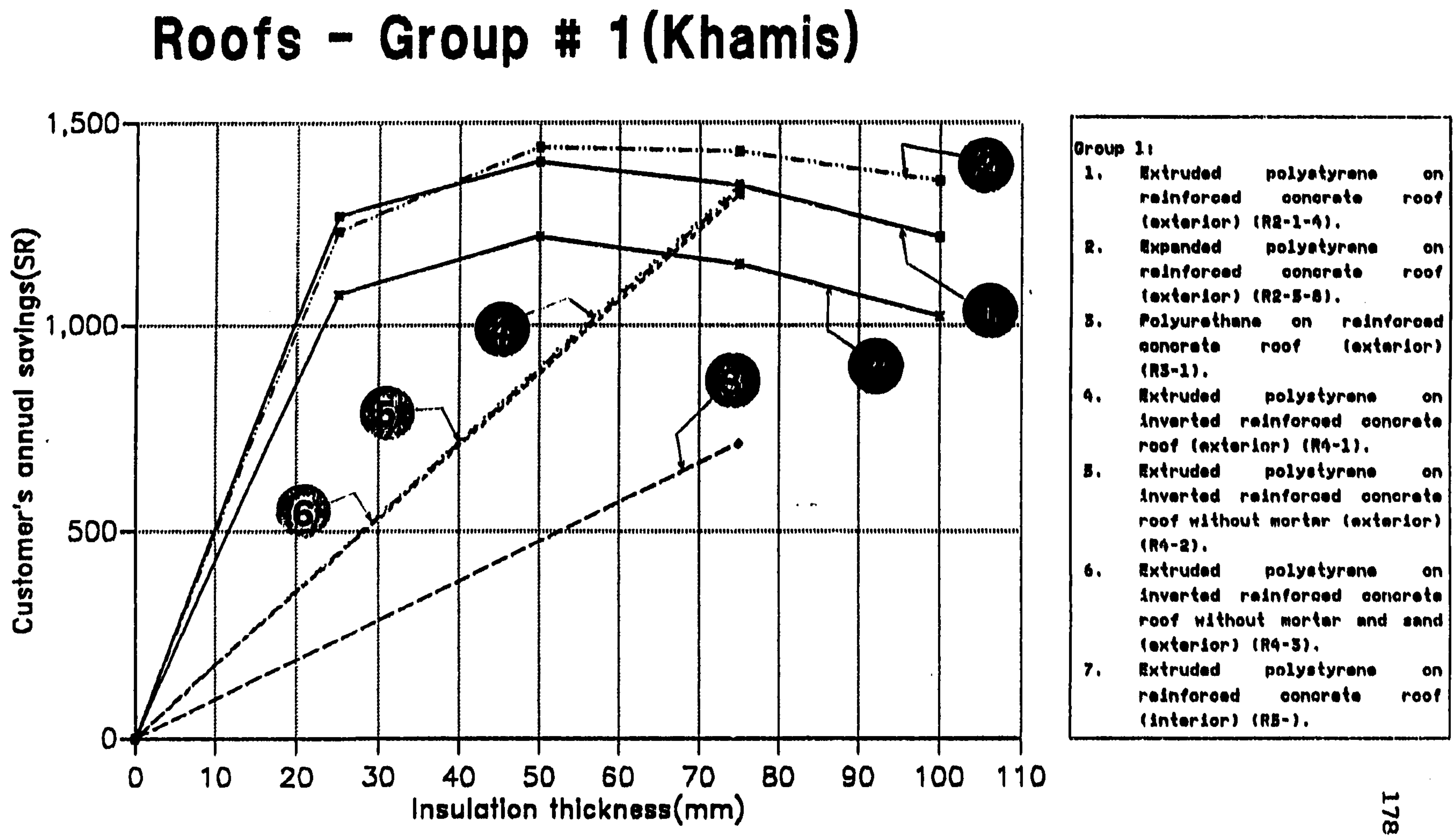


Figure 6.59: Khamis - Roofs # 1 (Economic performance).

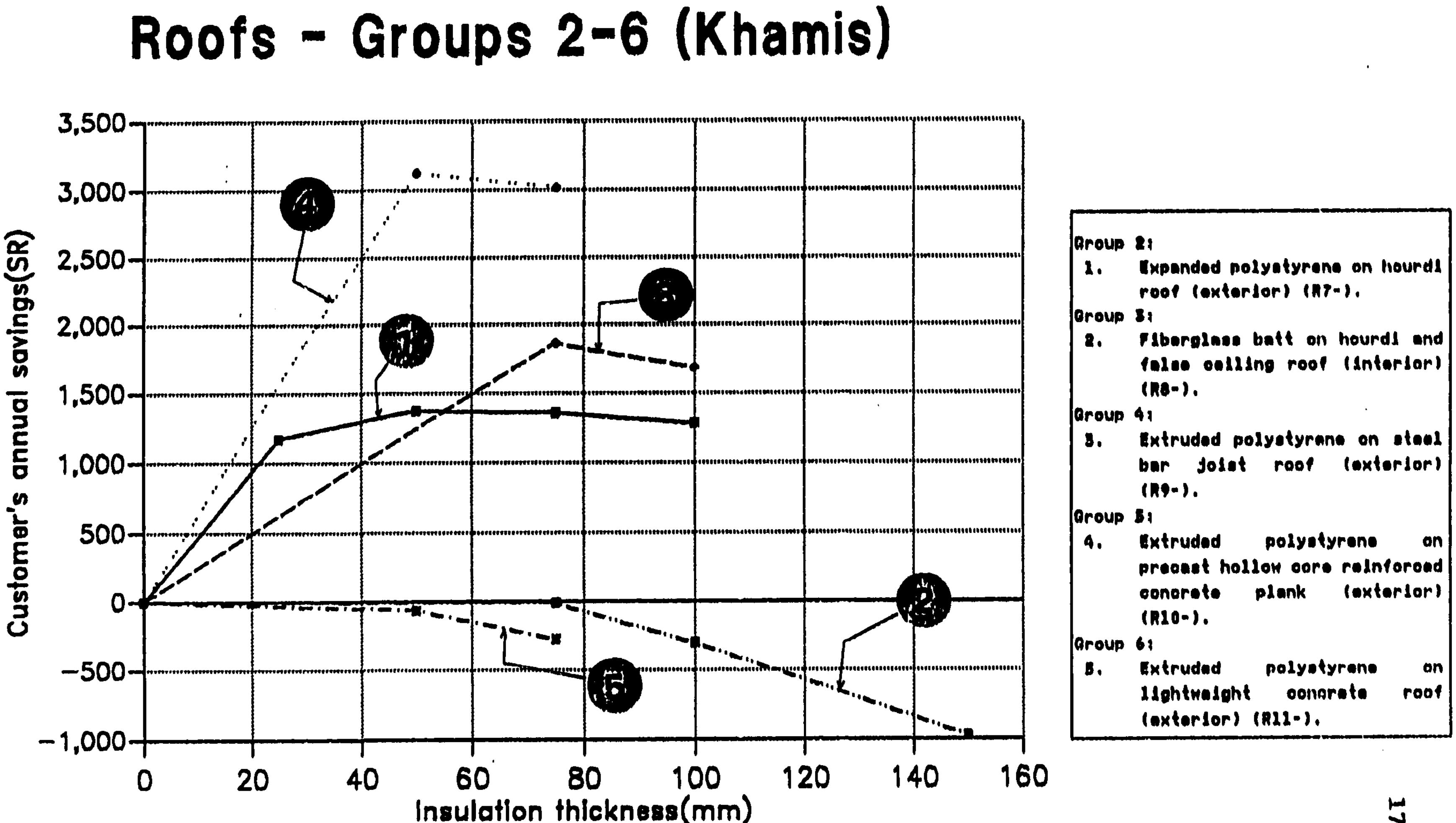


Figure 6.60: Khamis - Roofs # 2 - 6 (Economic performance).

6.1.4.5 Wall and roof U-values (Customers)

The following figures, Figures 6.61 through 6.64, represent the thermal performance of each variation within a group of walls or roofs versus the customer's annual savings. The extracted U-values from these figures are summarized in section 6.2.

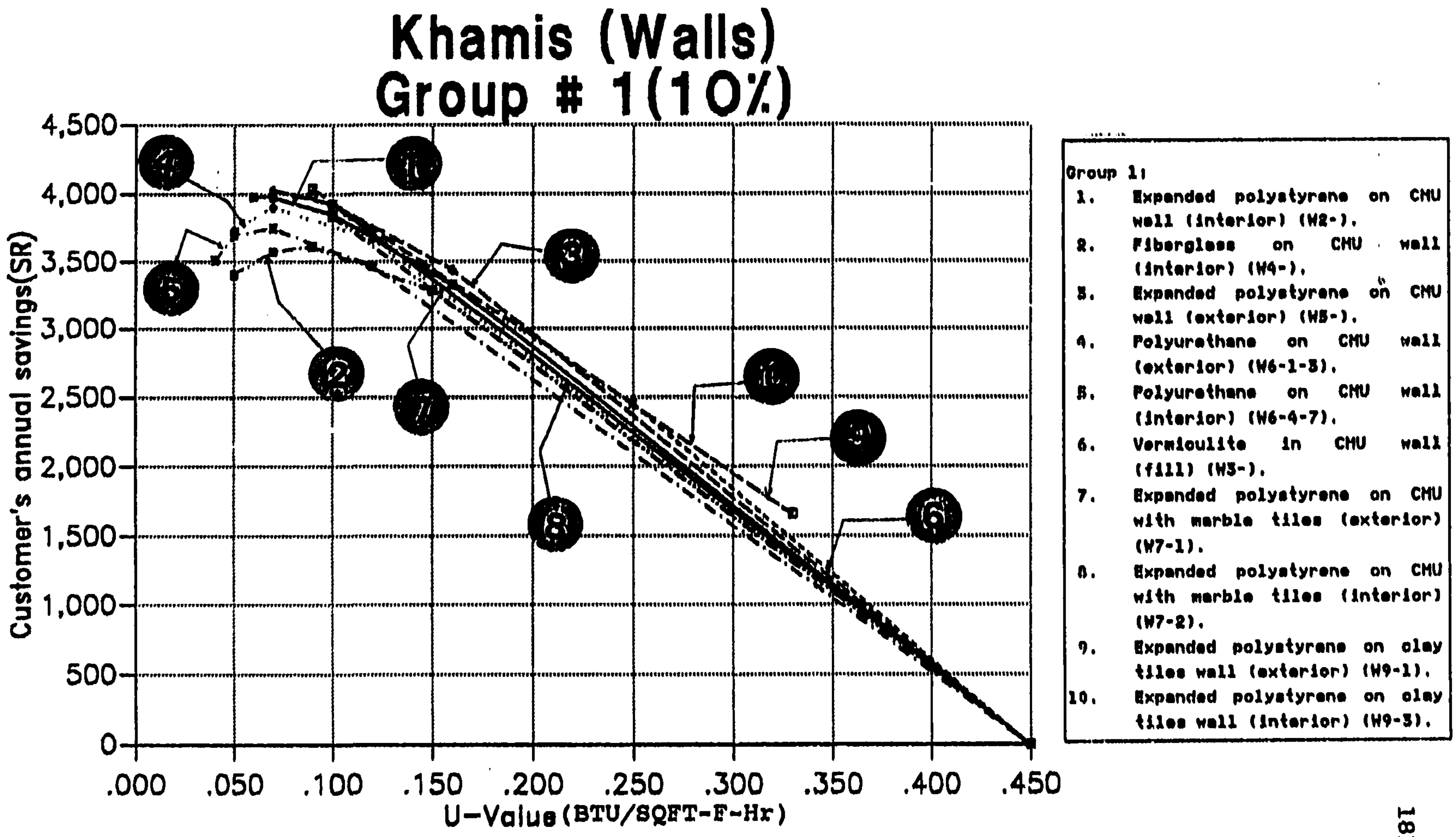
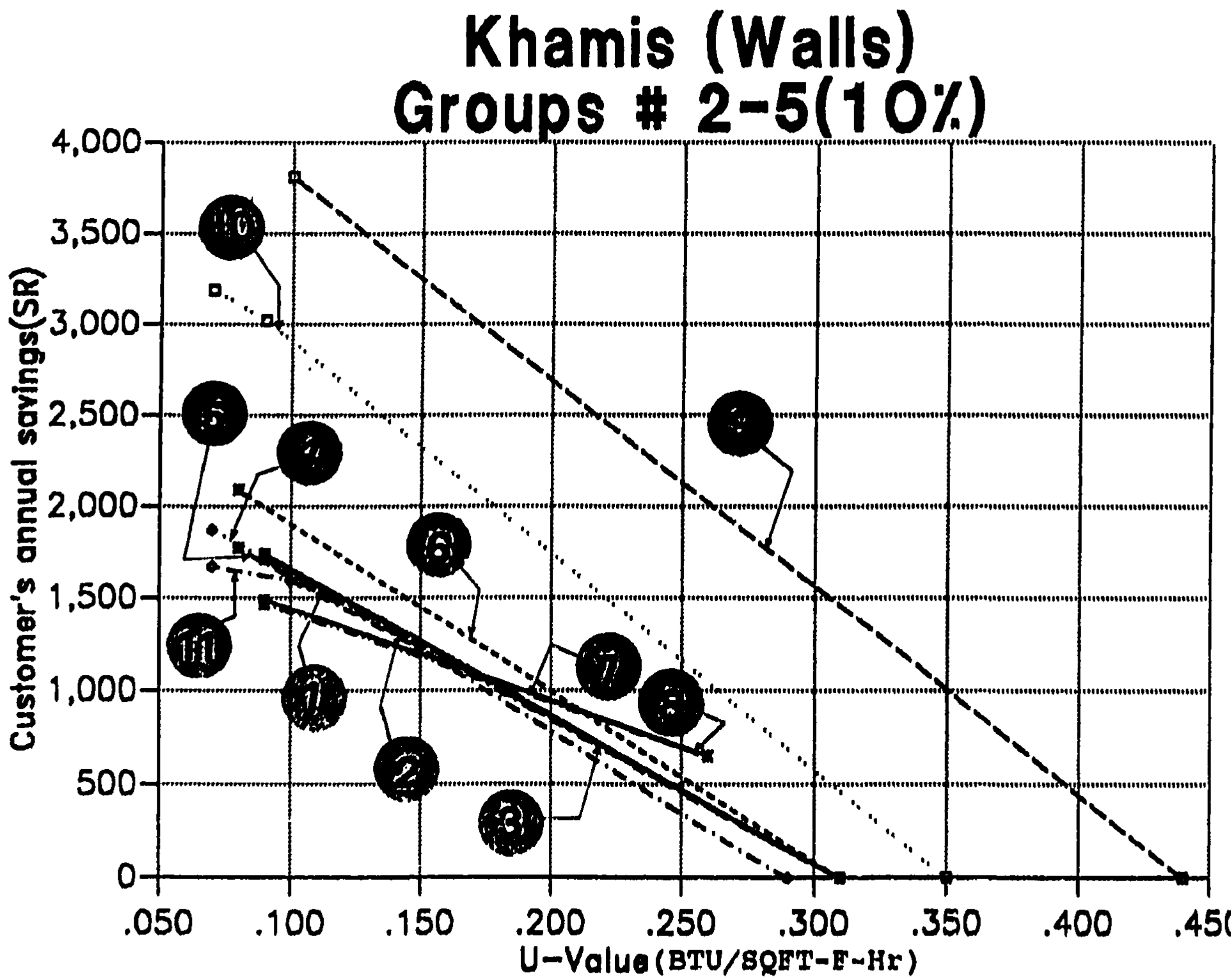


Figure 6.61: Khamis - Walls # 1 (Thermal performance (customer)).



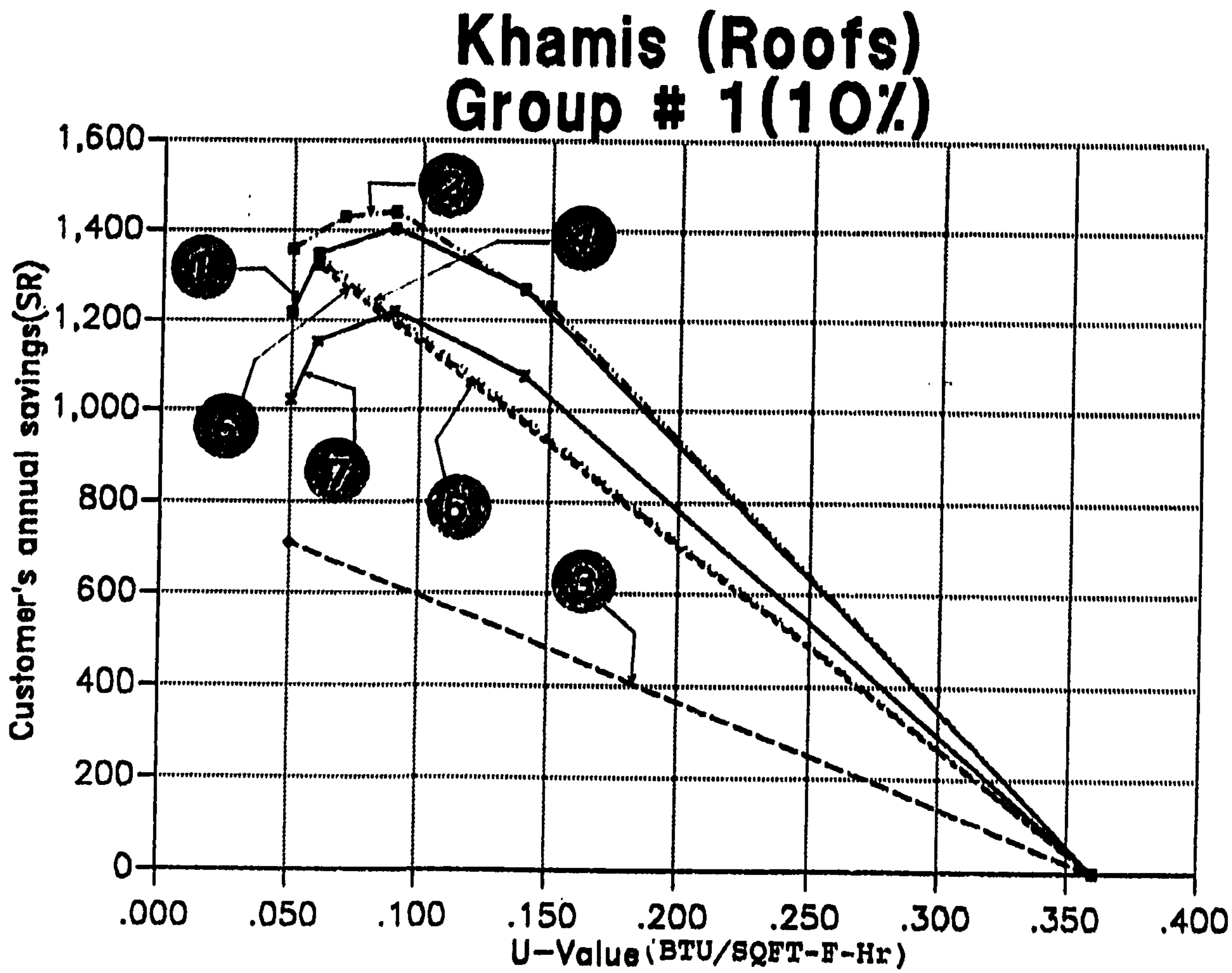
Group 2:
1. Expanded polystyrene in CMU and brick wall (exterior) (W8-1).
2. Expanded polystyrene in CMU and brick wall (interior) (W8-2).
3. Expanded polystyrene with airspace in CMU and brick wall (interior) (W8-3).
4. Fiberglass with reflective airspace in CMU and brick wall (exterior) (W10-1).
5. Fiberglass in CMU and brick wall (interior) (W10-3).
6. Fiberglass with no reflective airspace in CMU and brick wall (exterior) (W10-4).
7. Expanded polystyrene in clay tiles and brick wall (exterior) (W11-1).
8. Expanded polystyrene in clay tiles and brick wall (interior) (W11-3).

Group 3:
9. Expanded polystyrene on split faced block (interior) (W12-).

Group 4:
10. Fiberglass batt in metal studs (W13-).

Group 5:
11. Expanded polystyrene in cavity of two solid CMU walls (W14-).

Figure 6.62: Khamis - Walls # 2-5 (Thermal performance (customer)).



Group 1:

1. Extruded polystyrene on reinforced concrete roof (exterior) (R2-1-4).
2. Expanded polystyrene on reinforced concrete roof (exterior) (R2-5-8).
3. Polyurethane on reinforced concrete roof (exterior) (R3-1).
4. Extruded polystyrene on inverted reinforced concrete roof (exterior) (R4-1).
5. Extruded polystyrene on inverted reinforced concrete roof without mortar (exterior) (R4-2).
6. Extruded polystyrene on inverted reinforced concrete roof without mortar and sand (exterior) (R4-3).
7. Extruded polystyrene on reinforced concrete roof (interior) (R5-).

Figure 6.63: Khamis - Roofs # 1 (Thermal performance (customer)).

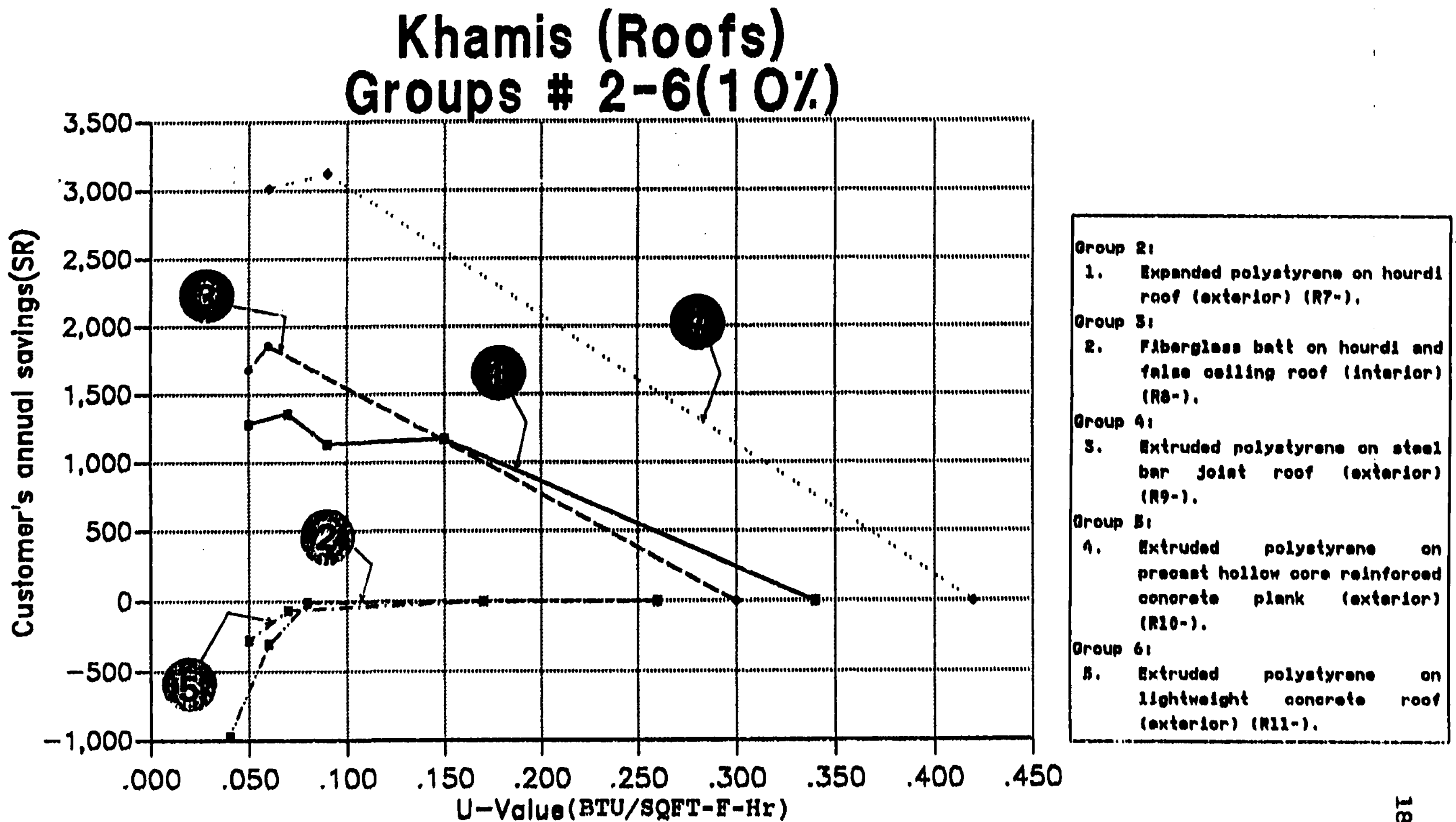
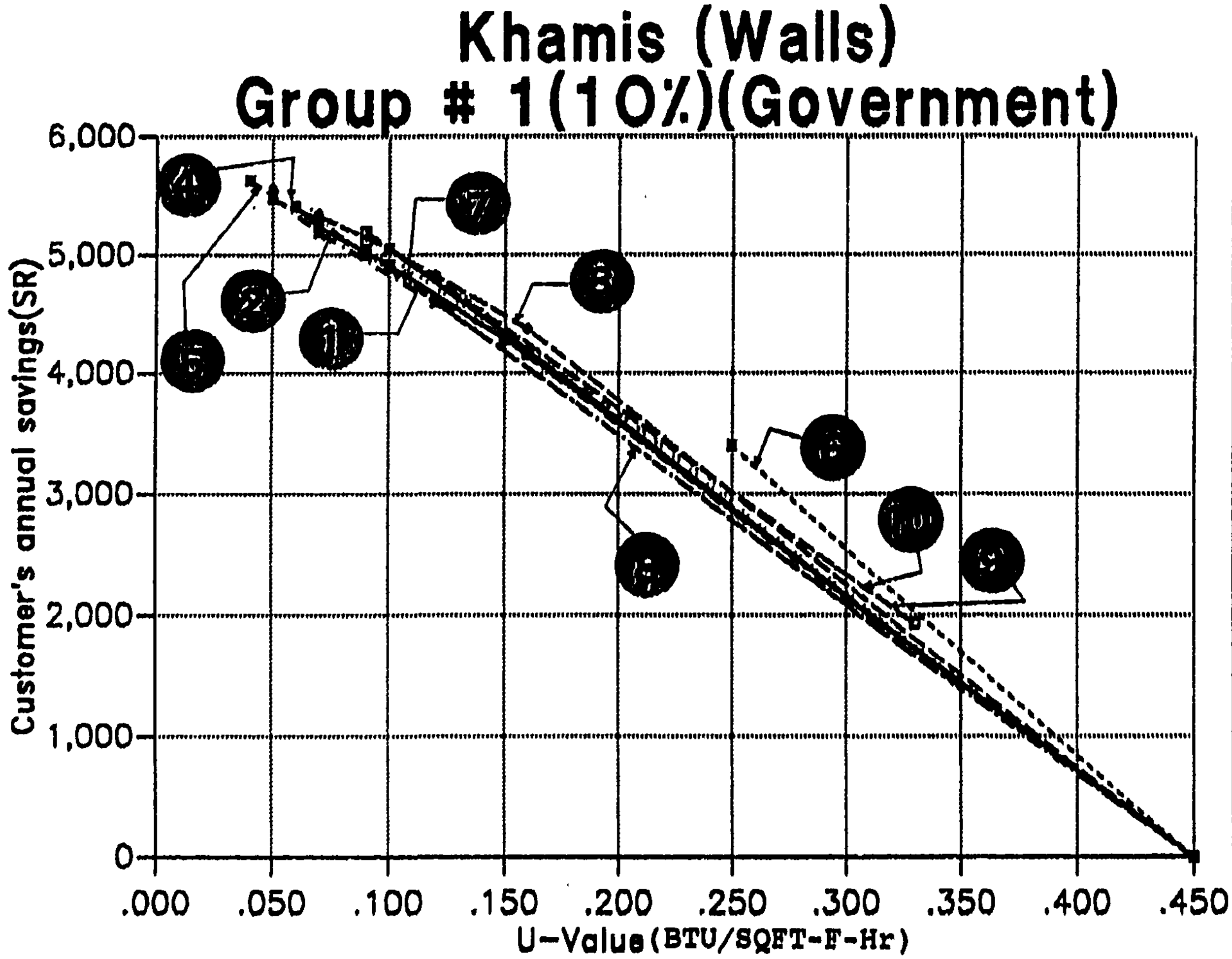


Figure 6.64: Khamis - Roofs # 2-6 (Thermal performance (customer)).

6.1.4.6 Wall and roof U-values (Government)

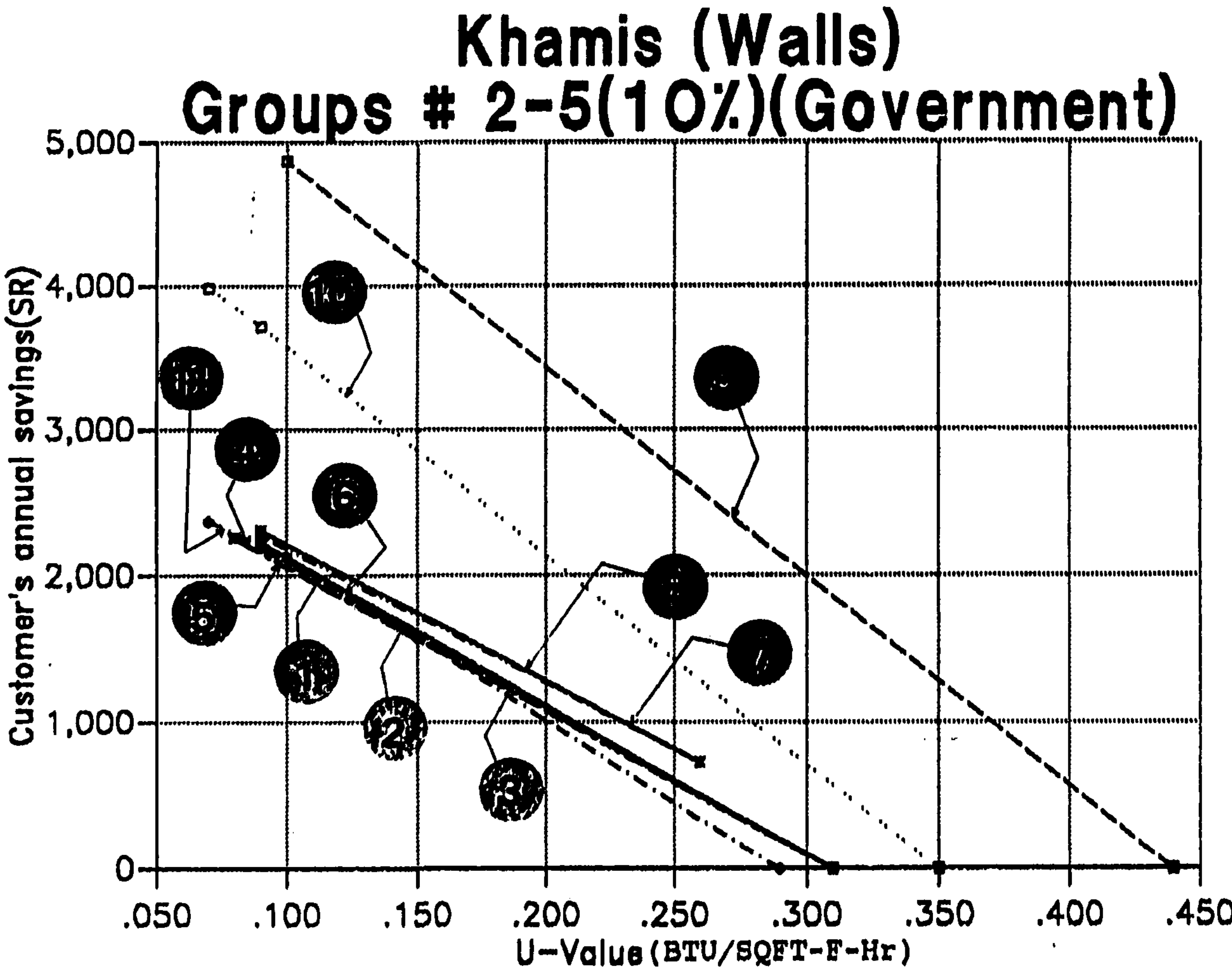
The following figures, Figures 6.65 through 6.68 represent the thermal performance of each variation versus the government's annual savings. The extracted U-values are summarized in section 6.2.



Group 1:

1. Expanded polystyrene on CMU wall (interior) (W2-).
2. Fiberglass on CMU wall (interior) (W4-).
3. Expanded polystyrene on CMU wall (exterior) (W5-).
4. Polyurethane on CMU wall (exterior) (W6-1-3).
5. Polyurethane on CMU wall (interior) (W6-4-7).
6. Vermiculite in CMU wall (fill) (W3-).
7. Expanded polystyrene on CMU with marble tiles (exterior) (W7-1).
8. Expanded polystyrene on CMU with marble tiles (interior) (W7-2).
9. Expanded polystyrene on clay tiles wall (exterior) (W9-1).
10. Expanded polystyrene on clay tiles wall (interior) (W9-3).

Figure 6.65: Khamis - Walls # 1 (Thermal performance (government)).



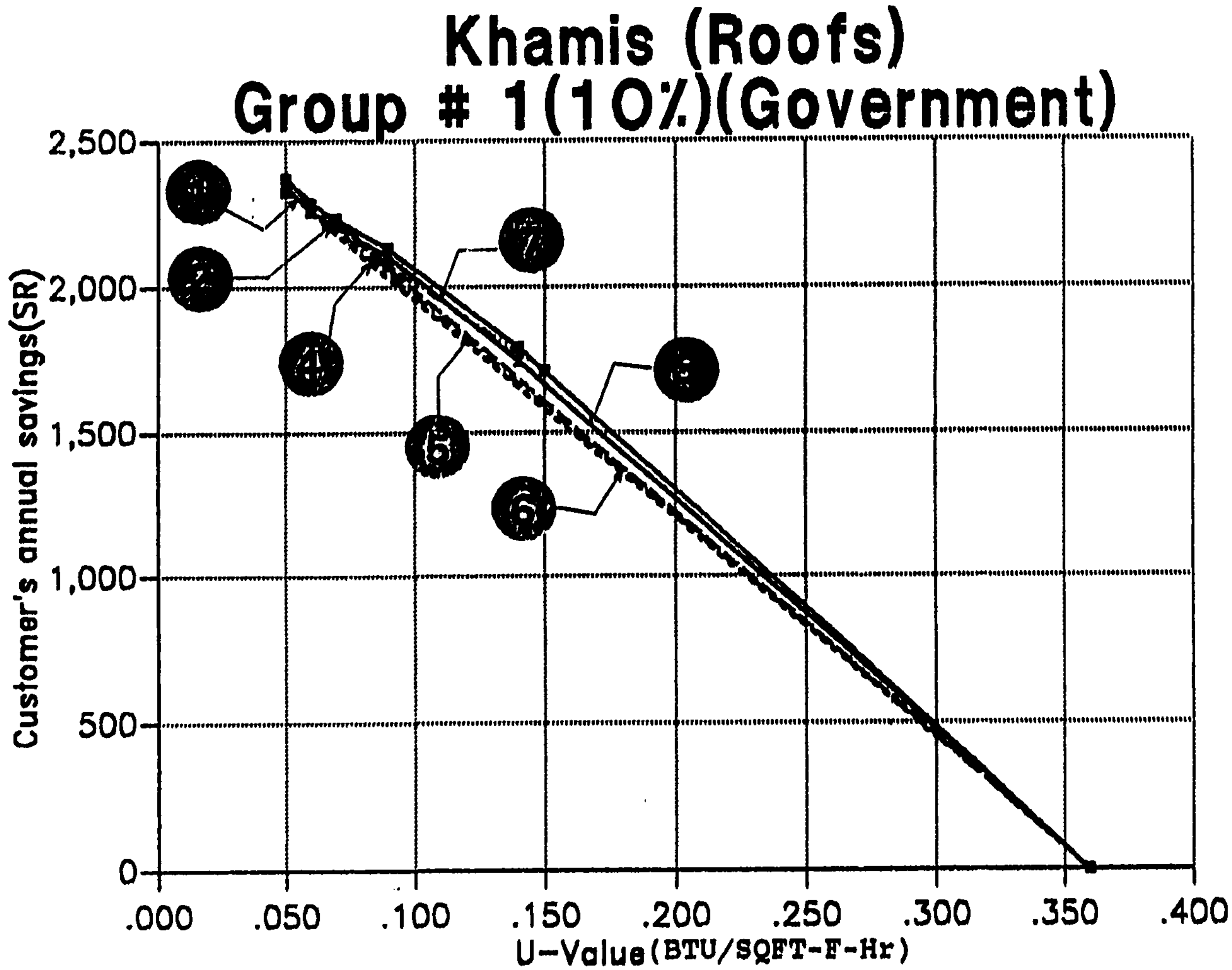
Group 2:
1. Expanded polystyrene in CMU and brick wall (exterior) (W8-1).
2. Expanded polystyrene in CMU and brick wall (interior) (W8-2).
3. Expanded polystyrene with airspace in CMU and brick wall (interior) (W8-3).
4. Fiberglass with reflective airspace in CMU and brick wall (exterior) (W10-1).
5. Fiberglass in CMU and brick wall (interior) (W10-3).
6. Fiberglass with no reflective airspace in CMU and brick wall (exterior) (W10-4).
7. Expanded polystyrene in clay tiles and brick wall (exterior) (W11-1).
8. Expanded polystyrene in clay tiles and brick wall (interior) (W11-3).

Group 3:
9. Expanded polystyrene on split faced block (interior) (W12-).

Group 4:
10. Fiberglass batt in metal studs (W13-).

Group 5:
11. Expanded polystyrene in cavity of two solid CMU walls (W14-).

Figure 6.66: Khamis - Walls # 2-5 (Thermal performance (government)).



Group 1:
1. Extruded polystyrene on reinforced concrete roof (exterior) (R2-1-4).
2. Expanded polystyrene on reinforced concrete roof (exterior) (R2-5-8).
3. Polyurethane on reinforced concrete roof (exterior) (R3-1).
4. Extruded polystyrene on inverted reinforced concrete roof (exterior) (R4-1).
5. Extruded polystyrene on inverted reinforced concrete roof without mortar (exterior) (R4-2).
6. Extruded polystyrene on inverted reinforced concrete roof without mortar and sand (exterior) (R4-3).
7. Extruded polystyrene on reinforced concrete roof (interior) (R5-).

Figure 6.67: Khamis - Roofs # 1 (Thermal performance (government)).

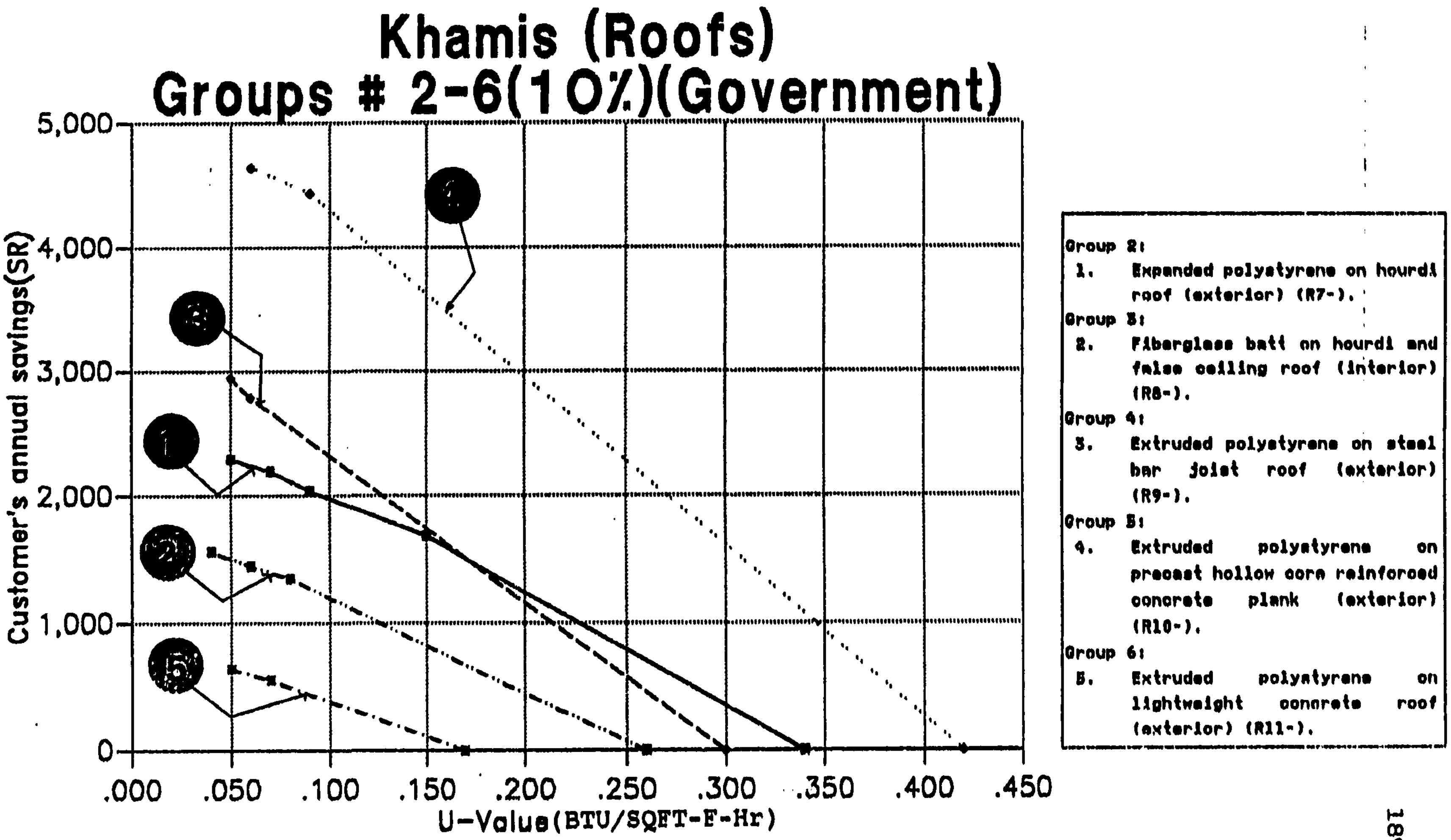


Figure 6.68: Khamis - Roofs # 2-6 (Thermal performance (government)).

6.2 Comparisons among the four cities

From the results presented in the previous section, comparisons among the four cities could be achieved as follows:

Wall configurations:

In group 1, for Dhahran, Riyadh, Jeddah and Khamis Mushait, the walls which give the maximum annual savings are walls W6-3, W2-4, W2-4 and W9-1, respectively. The corresponding customer's annual savings for these walls are SR 6097, SR 7865, SR 5719 and SR 4040, respectively.

In group 2, for Dhahran city, wall 10-1 gives the best customer's annual savings of about SR 3299. For Riyadh city, the best customer's annual savings of about SR 4175 is given by wall 10-4. In Jeddah, wall 10-4 gives the highest annual savings of about SR 3211. For Khamis Mushait city, wall 10-4 gives the best savings of about SR 2090.

In group 3, wall 12-1 gives Dhahran, Riyadh, Jeddah and Khamis Mushait annual savings of about SR 5439, SR 7238, SR 5302 and SR 3810, respectively.

In group 4, wall 13-2 gives Dhahran, Riyadh, Jeddah and Khamis Mushait annual savings of about SR 3664, SR 6115, SR 4191 and SR 3187, respectively.

In the last group, group 5, wall 14-4 gives Dhahran, Riyadh, Jeddah and Khamis Mushait annual savings of about SR 2309, SR 3788, SR 2810 and SR 1674, respectively.

Thus, it is obvious that insulation used in Riyadh city will be saving more than Dhahran and Jeddah cities while Khamis Mushait gives the least benefit compared to the other cities.

Roof configurations:

In group 1, for Dhahran city, roof R2-5 gives the best customer's annual savings of about SR 2713. For Riyadh city, roof R2-8 gives the best savings of about SR 3582. For Jeddah, roof R2-5 also gives the best savings of about SR 2508. Finally, for Khamis Mushait, roof R2-7 gives the best savings of about SR 1441.

In group 2, for Dhahran city, roof R7-3 gives the best customer's annual savings of about SR 2313. For Riyadh city, roof R7-4 gives the best savings of about SR 3352. For Jeddah, roof R7-1 gives the best savings of about SR 2369. Finally, for Khamis Mushait, roof R7-3 gives the best savings of about SR 1371.

In group 3, for Dhahran city, roof R8-3 is the only roof that gives savings, about SR 221. For Riyadh city, roof R8-2 gives the best savings of about SR 1326. For Jeddah, roof R8-2 gives the best savings of about SR 676. Finally, for Khamis Mushait, none of the roofs give savings.

In group 4, for all the cities, Dhahran, Riyadh, Jeddah and Khamis Mushait, roof R9-1 gives the best customer's annual savings of SR 1628 for Dhahran, SR 3558 for Riyadh, SR 2045 for Jeddah and SR 1860 for Khamis Mushait.

In group 5, for Dhahran city, roof R10-3 is the only roof that gives savings, about SR 2929. For Riyadh city, roof R10-1 gives the best savings, about SR 5594. For Jeddah, roof R10-3 gives the best savings, about SR 4053. Finally, for Khamis Mushait, roof R10-3 gives the best savings, about SR 3125.

In the last group, for Dhahran city, roof R11-1 gives the best customer's annual saving of about SR 1151. For Riyadh city, roof R11-3 gives the best saving of about SR 686. For Jeddah, roof R11-3 gives the best savings of about SR 374. Finally, for Khamis Mushait none of the roofs give savings.

Combined configurations:

For the combination insulation cases, in Dhahran city, the combinations of either W23R23 or W53R23 give the maximum customer's annual savings. For Riyadh city, the combinations of either W23R21 or W53R21 give the best customer's annual savings. For Jeddah city, the combinations that give the best customer's annual savings are W23R21 and W53R21. For Khamis Mushait, the combination of W53R23 give the best customer's annual savings.

Performance of materials:

For the expanded polystyrene board on CMU walls, the thickness of 75mm will give the best customer's annual savings in Dhahran and Khamis Mushait. In Riyadh and Jeddah, the 100mm thickness will give the best savings.

For the polyurethane board on CMU walls (interior), the thickness of 50mm will give the best customer's annual savings for all cities.

For the fiberglass on CMU walls, the thickness of 75mm will give the best customer's annual savings in Dhahran, Riyadh and Jeddah. In Khamis Mushait, the thickness of 50mm will give the best savings.

For the extruded polystyrene board on reinforced concrete roofs (interior), the thickness of 50mm will give the maximum customer's annual savings in Dhahran and Khamis Mushait. In Riyadh and Jeddah, the thickness of 75mm will give the maximum savings.

For the extruded polystyrene board on reinforced concrete roofs (exterior), the 50mm thickness will give the highest customer's annual savings in Khamis Mushait, while the 75mm thickness will give the best savings in Dhahran, Riyadh and Jeddah.

For the expanded polystyrene board on reinforced concrete roofs (exterior), the 50mm thickness will give the best savings only in Khamis Mushait, while the 75mm thickness will give the bast savings in Dhahran, Riyadh and Jeddah.

For the expanded polystyrene board on hourdi roofs (exterior), the 50mm thickness will give the maximum customer's annual savings in Khamis Mushait and Dhahran. In Riyadh and Jeddah, the 75mm thickness will give the maximum savings.

Comparison of U-values (Customers):

Tables 6.10 and 6.11 show a comparison of the maximum U-values for each group of walls and roofs for the Customers. A range of 10% from the maximum U-value is also given for the sake of giving allowances for the applications.

The maximum U-value is the one which gives the maximum annual saving. The range of 10% is got by calculating a range of plus and minus 10% from the highest annual saving.

Table 6.10: Summary of U-values (BTU/SQFT-F-Hr) (Walls / customers).

	Group # 1		Group # 2		Group # 3		Group # 4		Group # 5	
	Max.	Rang	Max.	Rang	Max.	Rang	Max.	Rang	Max.	Rang
DHAHRAN	0.05	0.05 0.12	0.07	0.07 0.1	0.1	0.1 0.13	0.07	0.07 0.1	0.07	0.07 0.12
RIYADH	0.06	0.04 0.12	0.08	0.07 0.11	0.1	0.1 0.14	0.07	0.07 0.1	0.07	0.07 0.1
JEDDAH	0.06	0.04 0.13	0.08	0.07 0.1	0.1	0.1 0.13	0.07	0.07 0.1	0.07	0.07 0.1
KHAMIS M	0.09	0.04 0.15	0.08	0.07 0.1	0.1	0.1 0.13	0.07	0.07 0.1	0.07	0.07 0.11

Table 6.11: Summary of U-values (BTU/SQFT-F-Hr) (Roofs / customers).

	Group # 1		Group # 2		Group # 3		Group # 4		Group # 5		Group # 6	
	Max.	Rang	Max.	Rang	Max.	Rang	Max.	Rang	Max.	Rang	Max.	Rang
DHAHRAN	0.07	0.05 0.08	0.09	0.08 0.13	0.04	0.04 0.05	0.06	0.05 0.07	0.09	0.06 0.11	0.05	0.05 0.06
RIYADH	0.05	0.05 0.11	0.05	0.05 0.1	0.08	0.06 0.12	0.06	0.05 0.09	0.06	0.06 0.12	0.07	0.05 0.1
JEDDAH	0.07	0.05 0.11	0.07	0.05 0.13	0.08	0.06 0.11	0.06	0.05 0.08	0.09	0.06 0.13	0.07	0.05 0.11
KHAMIS M	0.09	0.05 0.13	0.07	0.05 0.09	X	X X	0.06	0.05 0.08	0.09	0.06 0.13	X	X X

X : Not applicable.

Comparison of U-values (Government):

Tables 6.12 and 6.13 show a comparison of the maximum U-values for each group of walls and roofs for the government. The range of 10% from the maximum U-value is also given.

Table 6.12: **Summary of U-values (BTU/SQFT-F-Hr) (Walls / government).**

	Group # 1		Group # 2		Group # 3		Group # 4		Group # 5	
	Max.	Rang	Max.	Rang	Max.	Rang	Max.	Rang	Max.	Rang
DHAHRAN	0.05	0.05 0.07	0.07	0.07 0.1	0.1	0.1 0.13	0.07	0.07 0.1	0.07	0.07 0.11
RIYADH	0.04	0.04 0.08	0.07	0.07 0.1	0.1	0.1 0.14	0.07	0.07 0.1	0.07	0.07 0.11
JEDDAH	0.04	0.04 0.09	0.07	0.07 0.1	0.1	0.1 0.13	0.07	0.07 0.1	0.07	0.07 0.1
KHAMIS M	0.04	0.04 0.09	0.07	0.07 0.11	0.1	0.1 0.14	0.07	0.07 0.1	0.07	0.07 0.1

Table 6.13: **Summary of U-values (BTU/SQFT-F-Hr) (Roofs / government).**

	Group # 1		Group # 2		Group # 3		Group # 4		Group # 5		Group # 6	
	Max.	Rang	Max.	Rang	Max.	Rang	Max.	Rang	Max.	Rang	Max.	Rang
DHAHRAN	0.05	0.05 0.08	0.09	0.07 0.12	0.04	0.04 0.05	0.05	0.05 0.07	0.06	0.06 0.1	0.07	0.05 0.08
RIYADH	0.05	0.05 0.09	0.05	0.05 0.08	0.04	0.04 0.07	0.05	0.05 0.08	0.06	0.06 0.1	0.05	0.05 0.07
JEDDAH	0.05	0.05 0.09	0.05	0.05 0.08	0.04	0.04 0.07	0.05	0.05 0.08	0.06	0.06 0.1	0.05	0.05 0.07
KHAMIS M	0.05	0.05 0.1	0.05	0.05 0.09	0.04	0.04 0.07	0.05	0.05 0.08	0.06	0.06 0.11	0.05	0.05 0.07

Chapter 7
SENSITIVITY ANALYSIS

7.1 Introduction

Prior to the application of an economic evaluation technique, the study period length (discount period), which is defined as the time period over which the costs of an investment are analyzed, and the energy price escalation rate (discount rate), which is defined as the rate of cost increase assumed for a given type of energy, are two basic assumptions that must be established [26]. The discount period may reflect the useful life of the investment or the time horizon of the investor, while the discount rate will reflect the investor's expected inflation rate for energy costs.

In this study, the discount period was selected as average values based on a market survey. Each economic parameter in this study has its own discount period. As seen in Table 4.3, for the electrical transformers and cables, the discount period is selected to be 25 years. For the air conditioning system, the discount period is 10 years. The thermal insulation materials are considered to have the same lifetime as the building.

A discount rate of 10% was first selected as a discount rate for this study. In order to see the effect of the discount rate on this study, two other discount rates (5% and 15%) were selected and used throughout the sensitivity analysis. These two rates were selected to see what happens if the discount rate is less than the selected 10% or it is greater than the selected 10%.

7.2 5% Discount rate

A 5% discount rate was selected to see the effect of a less than 10% discount rate on the thermal performance of the thermal insulation materials.

Figures 7.1 through 7.16 represent the thermal performance of each material within its group (walls and roofs) versus the customer's annual savings at a discount rate of 5%.

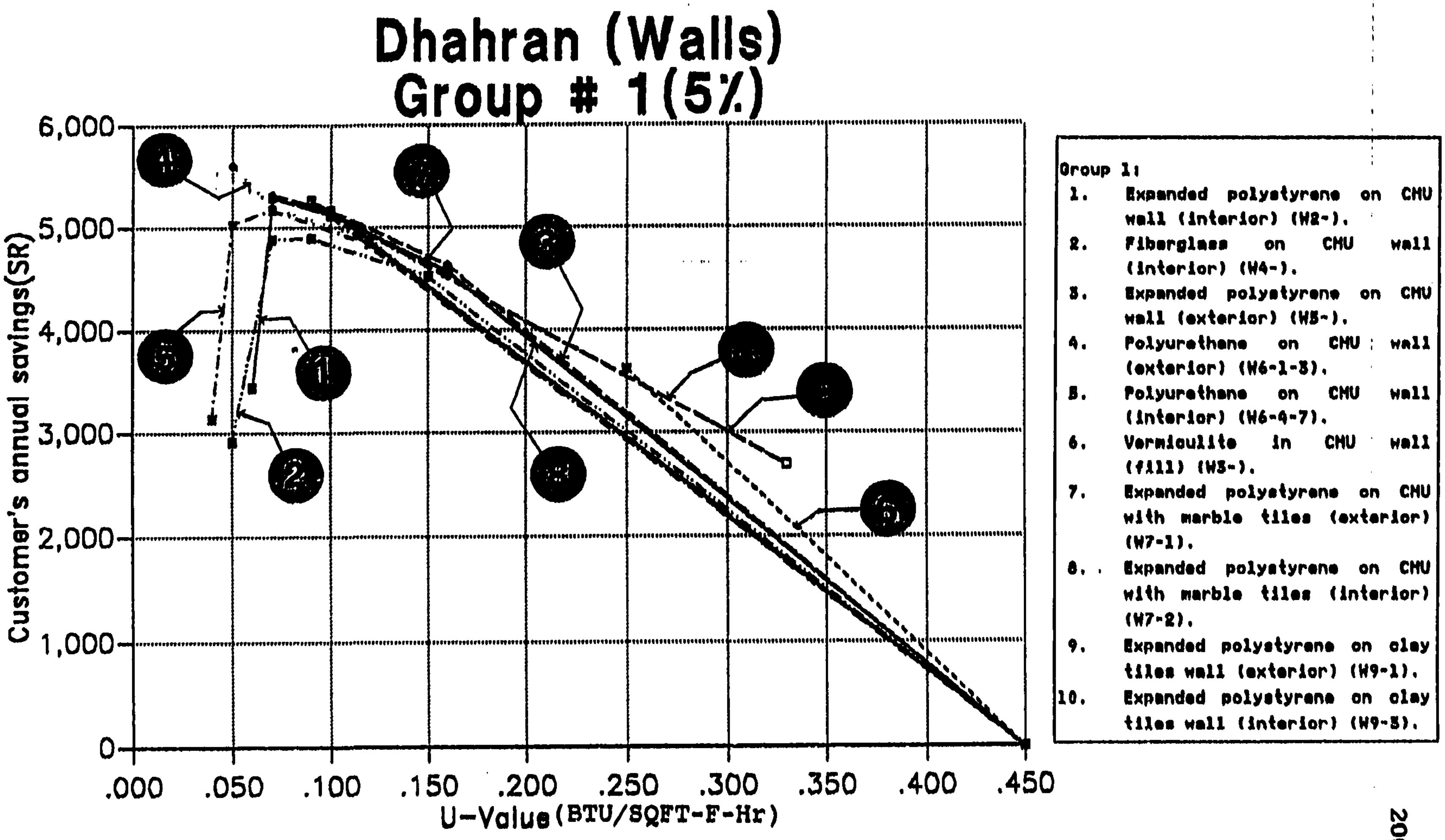
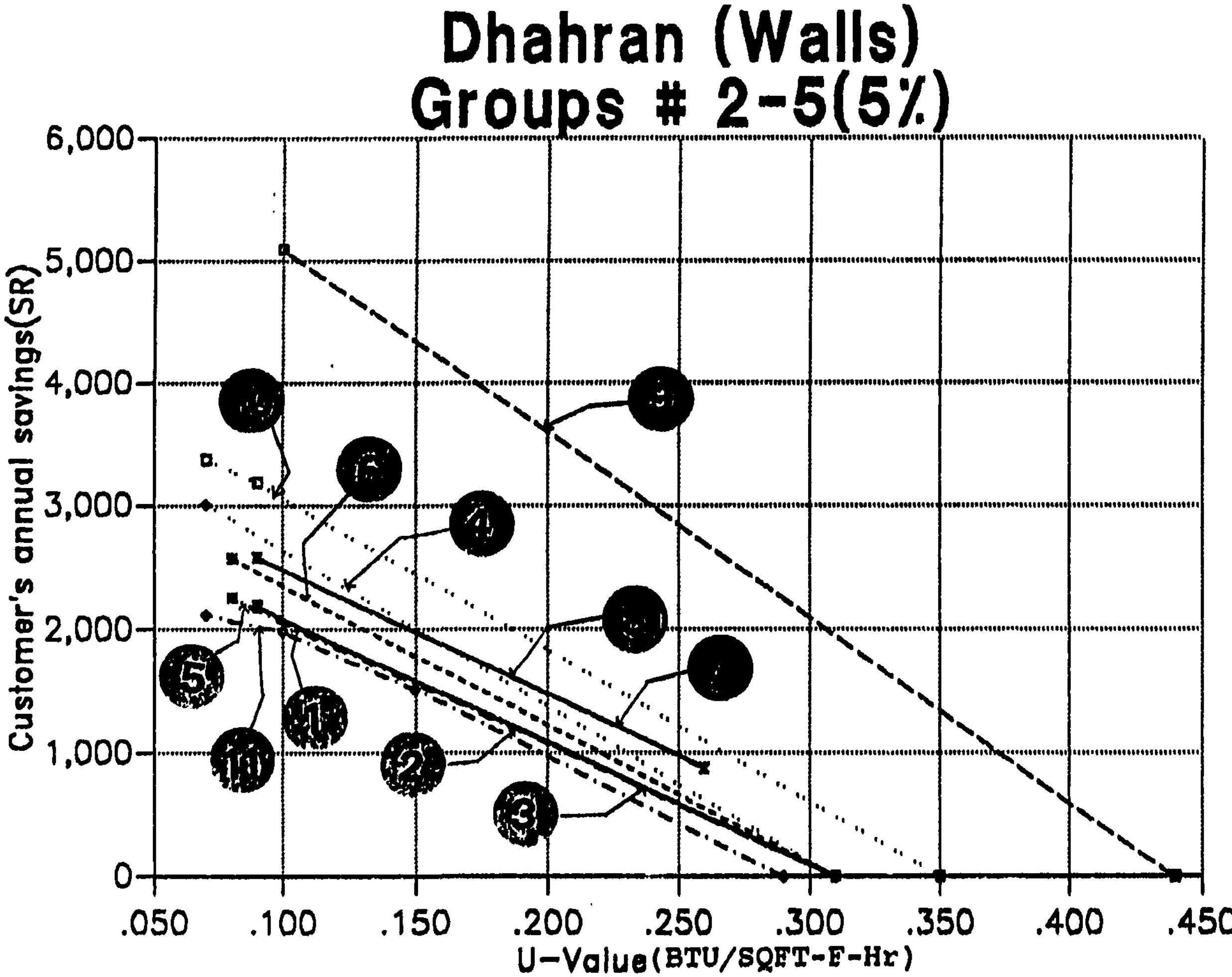


Figure 7.1: Dhahran - Walls # 1 (Thermal performance at 5%)



Group 2:
1. Expanded polystyrene in CMU and brick wall (exterior) (W8-1).
2. Expanded polystyrene in CMU and brick wall (interior) (W8-2).
3. Expanded polystyrene with airspace in CMU and brick wall (interior) (W8-3).
4. Fiberglass with reflective airspace in CMU and brick wall (exterior) (W10-1).
5. Fiberglass in CMU and brick wall (interior) (W10-3).
6. Fiberglass with no reflective airspace in CMU and brick wall (exterior) (W10-4).
7. Expanded polystyrene in clay tiles and brick wall (exterior) (W11-1).
8. Expanded polystyrene in clay tiles and brick wall (interior) (W11-3).

Group 3:
9. Expanded polystyrene on split faced block (interior) (W12-).

Group 4:
10. Fiberglass batt in metal studs (W13-).

Group 5:
11. Expanded polystyrene in cavity of two solid CMU walls (W14-).

Figure 7.2: Dhahran - Walls # 2-5 (Thermal performance at 5%)

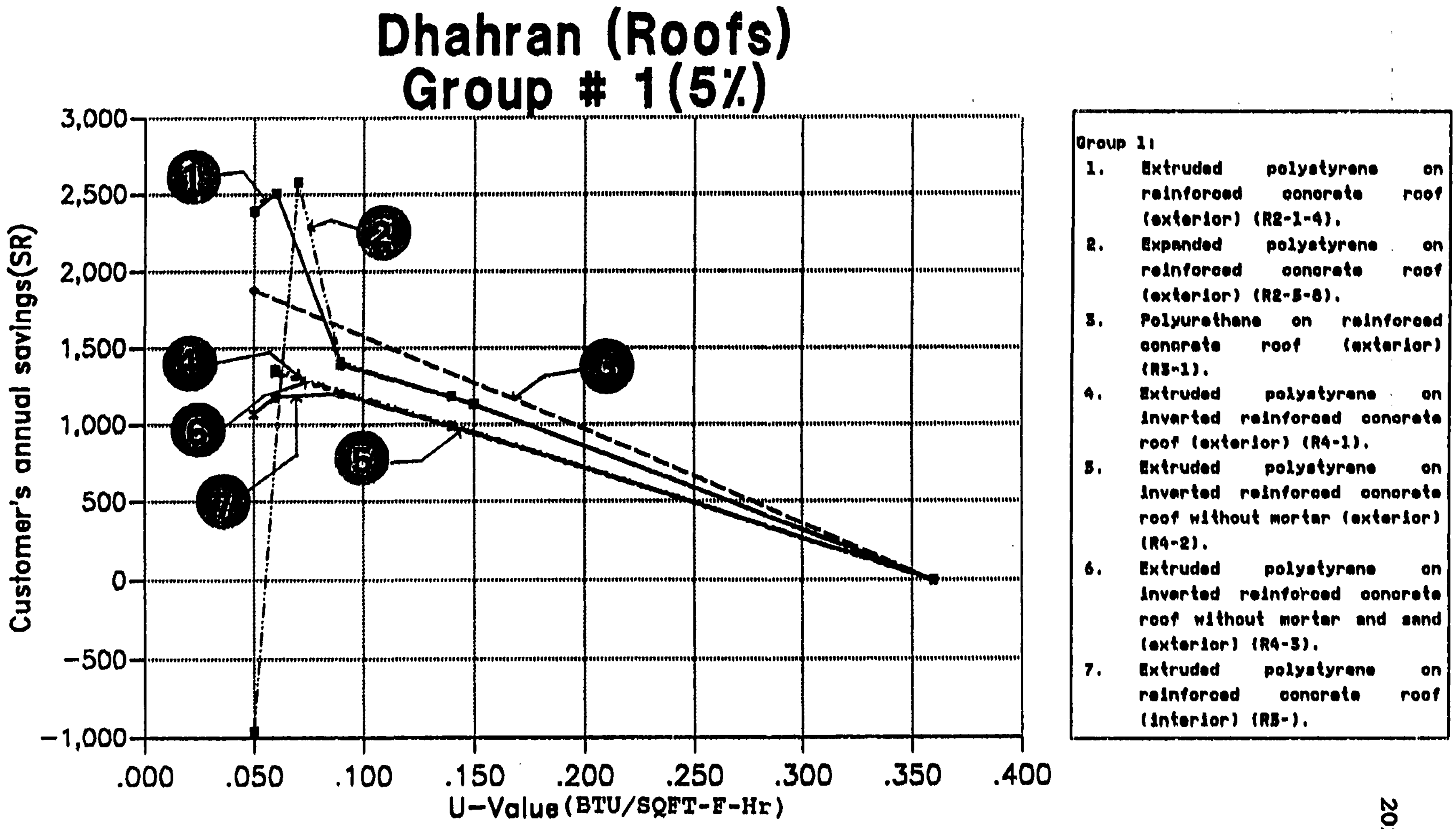


__Figure 7.3__: Dhahran - Roofs # 1 (Thermal performance at 5%)

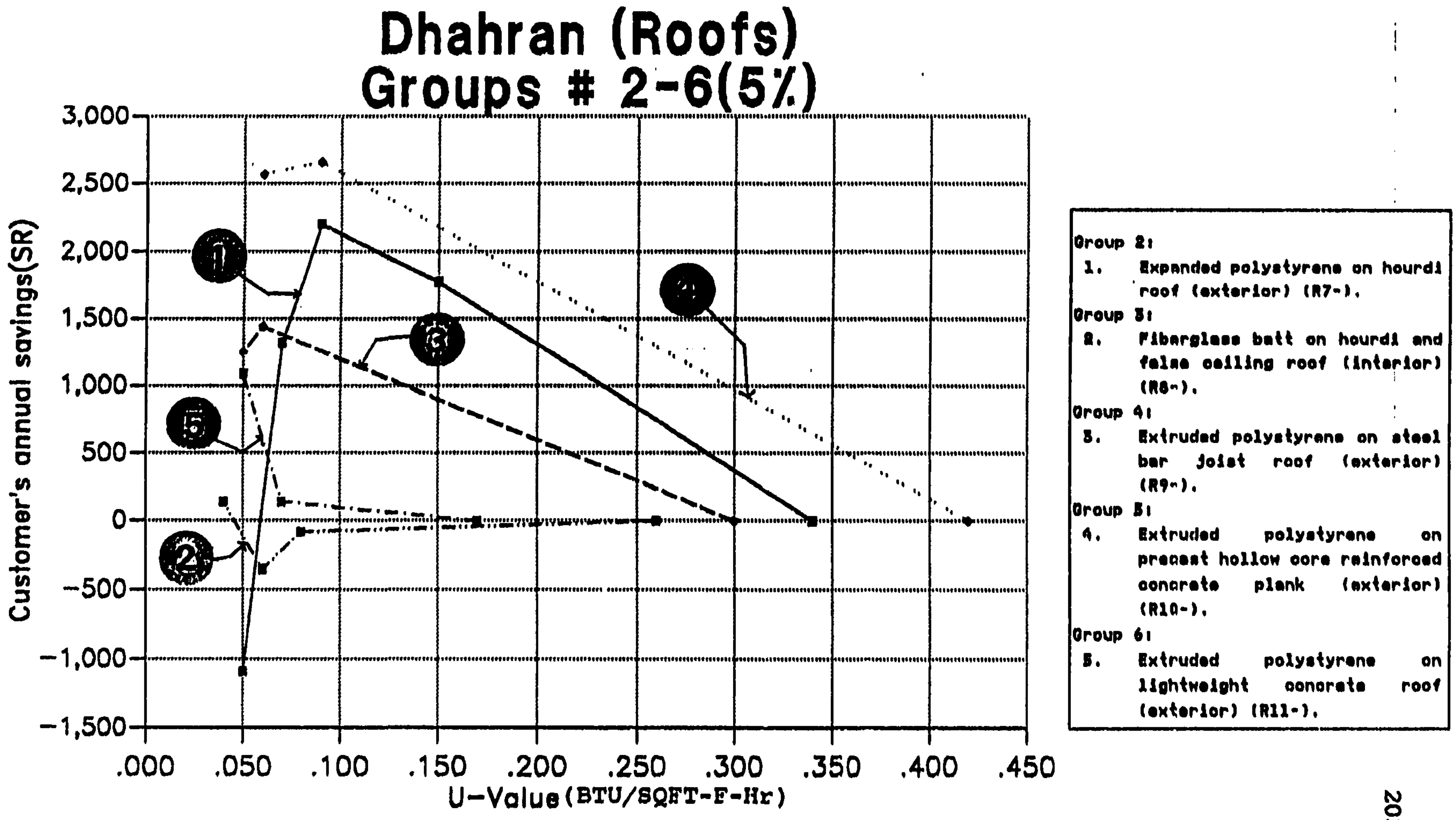
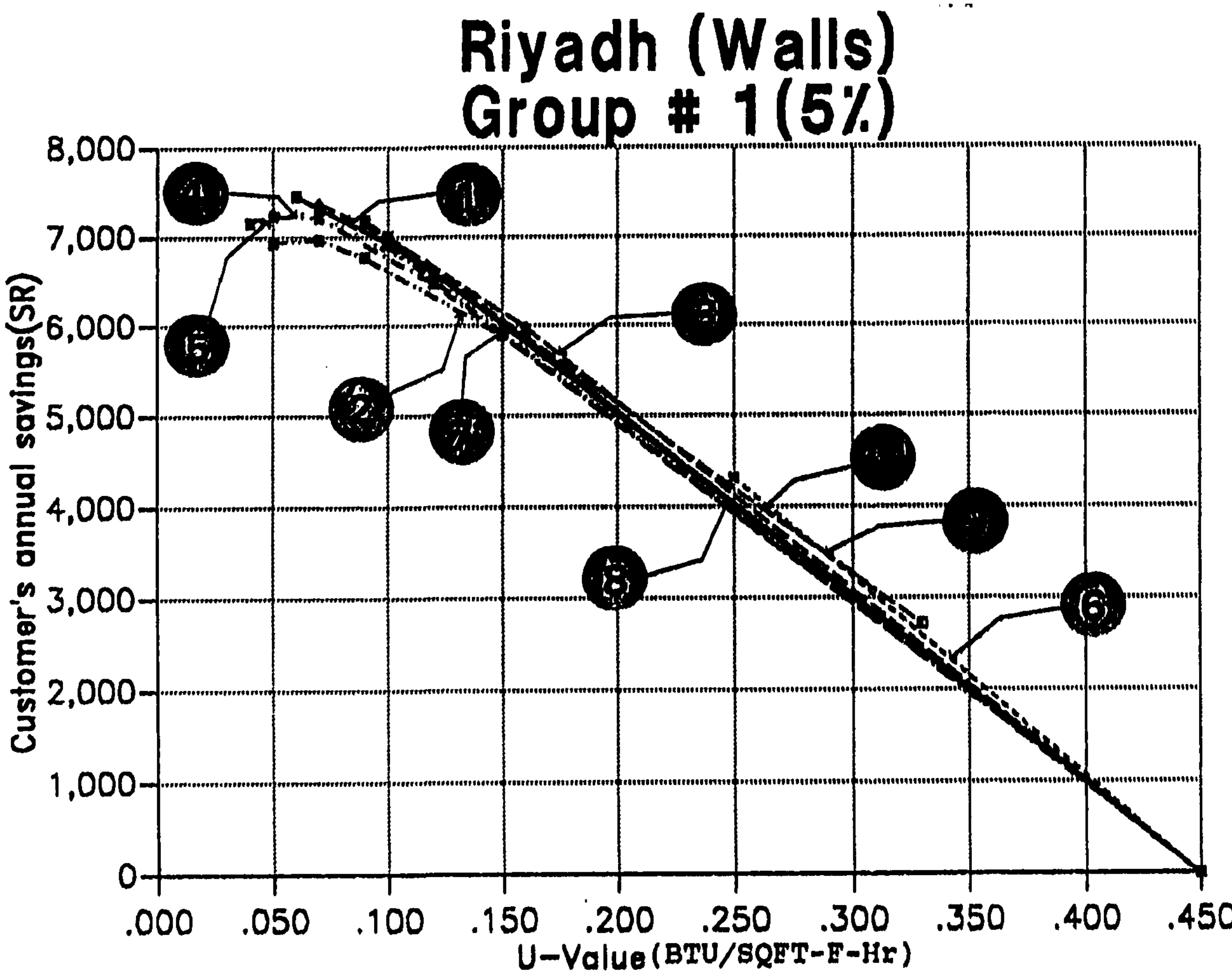


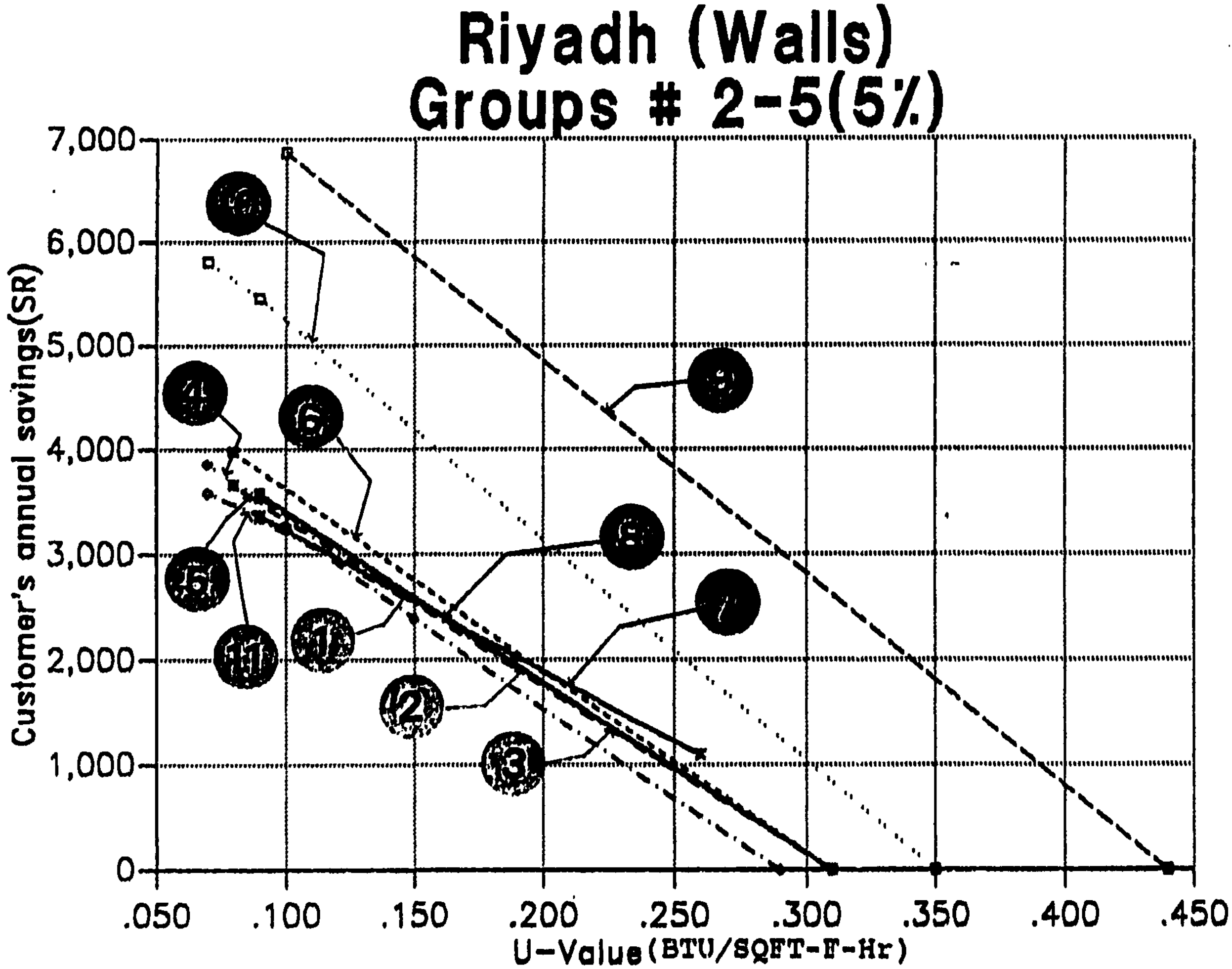
__Figure 7.4__: Dhahran - Roofs # 2-6 (Thermal performance at 5%)



Group 1:

1. Expanded polystyrene on CMU wall (interior) (W2-).
2. Fiberglass on CMU wall (interior) (W4-).
3. Expanded polystyrene on CMU wall (exterior) (W5-).
4. Polyurethane on CMU wall (exterior) (W6-1-3).
5. Polyurethane . on CMU wall (interior) (W6-4-7).
6. Vermiculite in CMU wall (fill) (W3-).
7. Expanded polystyrene on CMU with marble tiles (exterior) (W7-1).
8. Expanded polystyrene on CMU with marble tiles (interior) (W7-2).
9. Expanded polystyrene on clay tiles wall (exterior) (W9-1).
10. Expanded polystyrene on clay tiles wall (interior) (W9-3).

Figure 7.5: Riyadh - Walls # 1 (Thermal performance at 5%)



Group 2:

1. Expanded polystyrene in CMU and brick wall (exterior) (W8-1).
2. Expanded polystyrene in CMU and brick wall (interior) (W8-2).
3. Expanded polystyrene with airspace in CMU and brick wall (interior) (W8-3).
4. Fiberglass with reflective airspace in CMU and brick wall (exterior) (W10-1).
5. Fiberglass in CMU and brick wall (interior) (W10-3).
6. Fiberglass with no reflective airspace in CMU and brick wall (exterior) (W10-4).
7. Expanded polystyrene in clay tiles and brick wall (exterior) (W11-1).
8. Expanded polystyrene in clay tiles and brick wall (interior) (W11-3).

Group 3:

9. Expanded polystyrene on split faced block (interior) (W12-).

Group 4:

10. Fiberglass batt in metal studs (W13-).

Group 5:

11. Expanded polystyrene in cavity of two solid CMU walls (W14-).

Figure 7.6: Riyadh - Walls # 2-5 (Thermal performance at 5%)

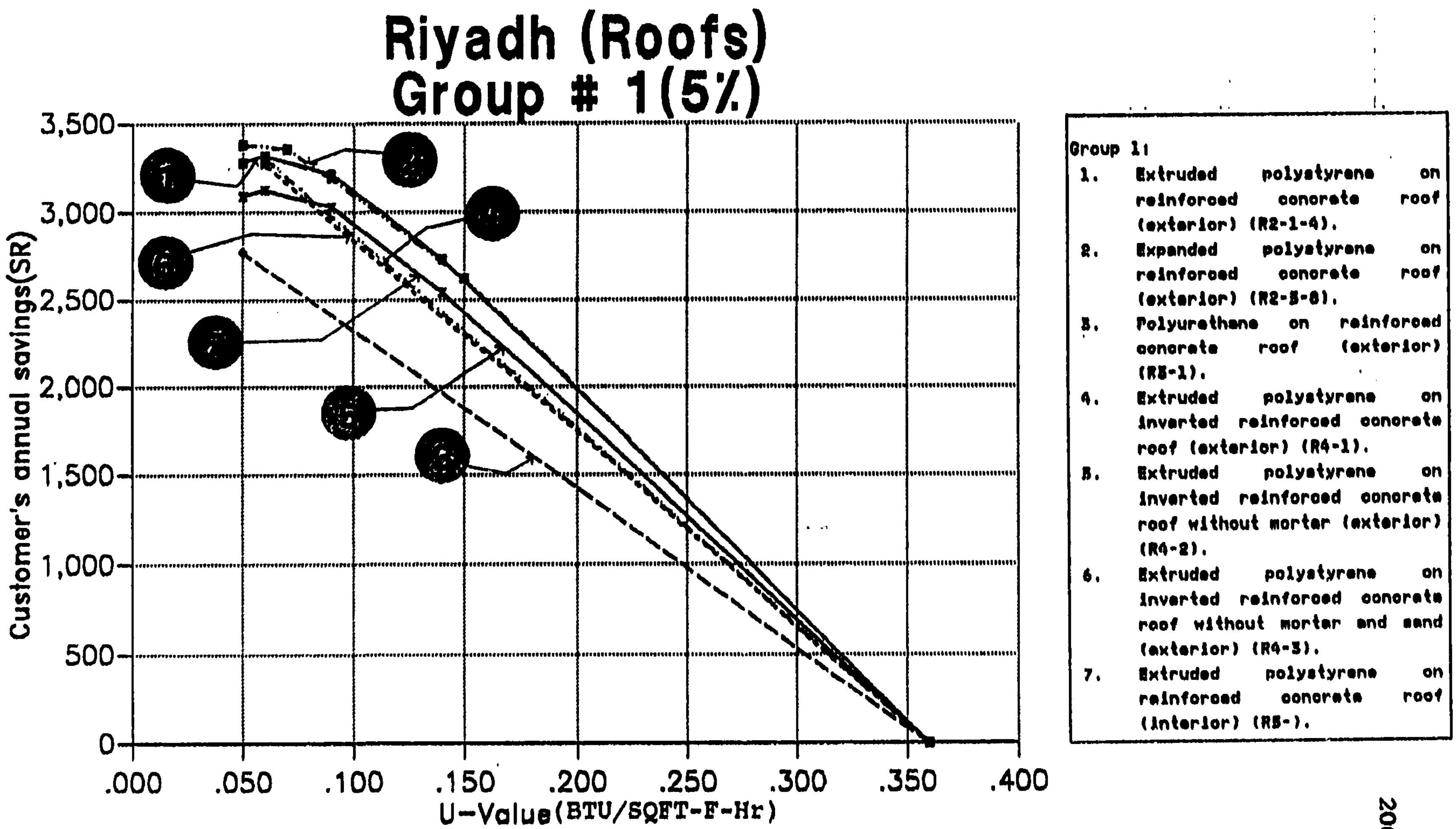
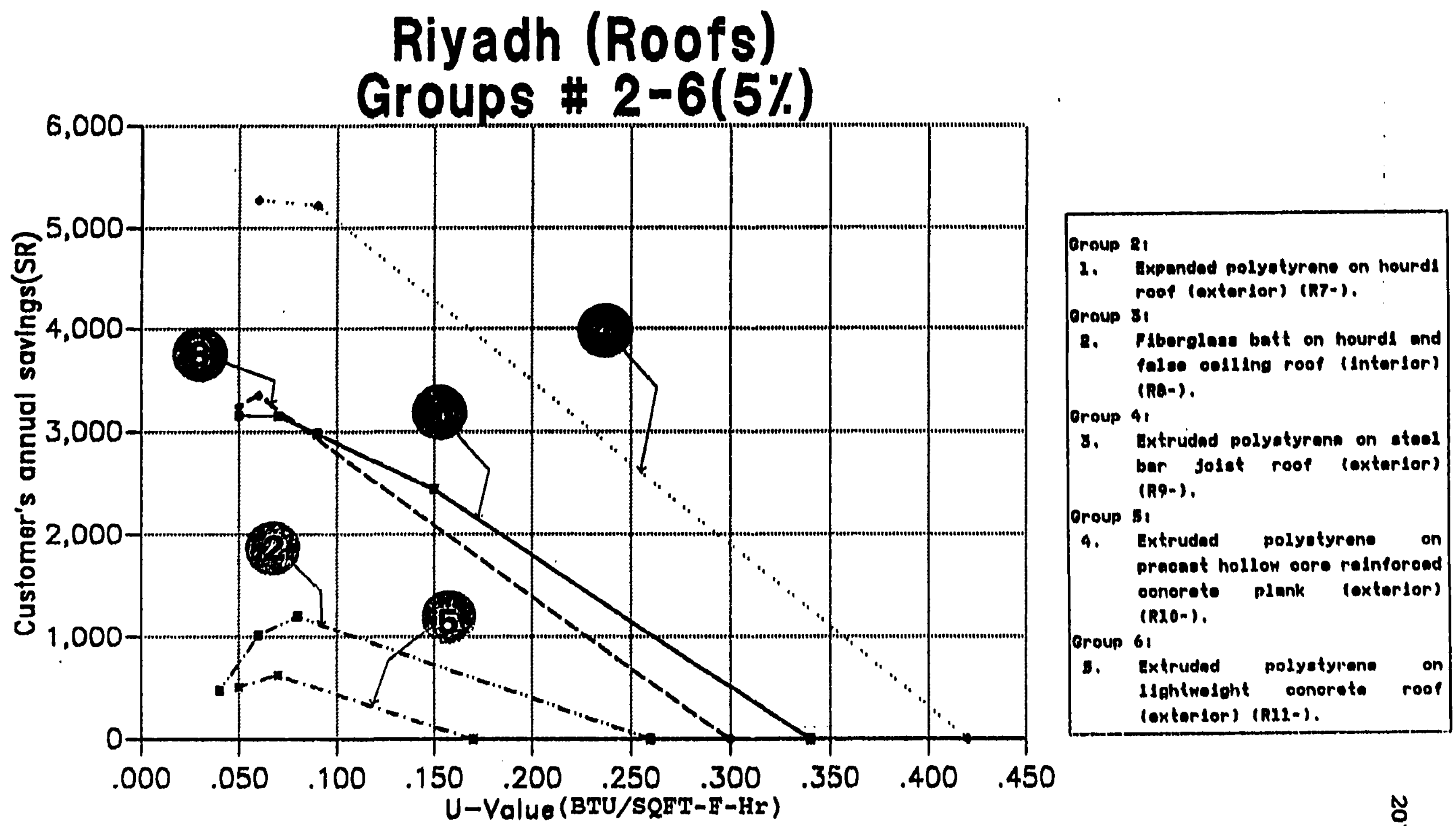


__Figure 7.7__: Riyadh - Roofs # 1 (Thermal performance at 5%)



<u>Figure 7.8</u>: Riyadh - Roofs # 2-6 (Thermal performance at 5%)

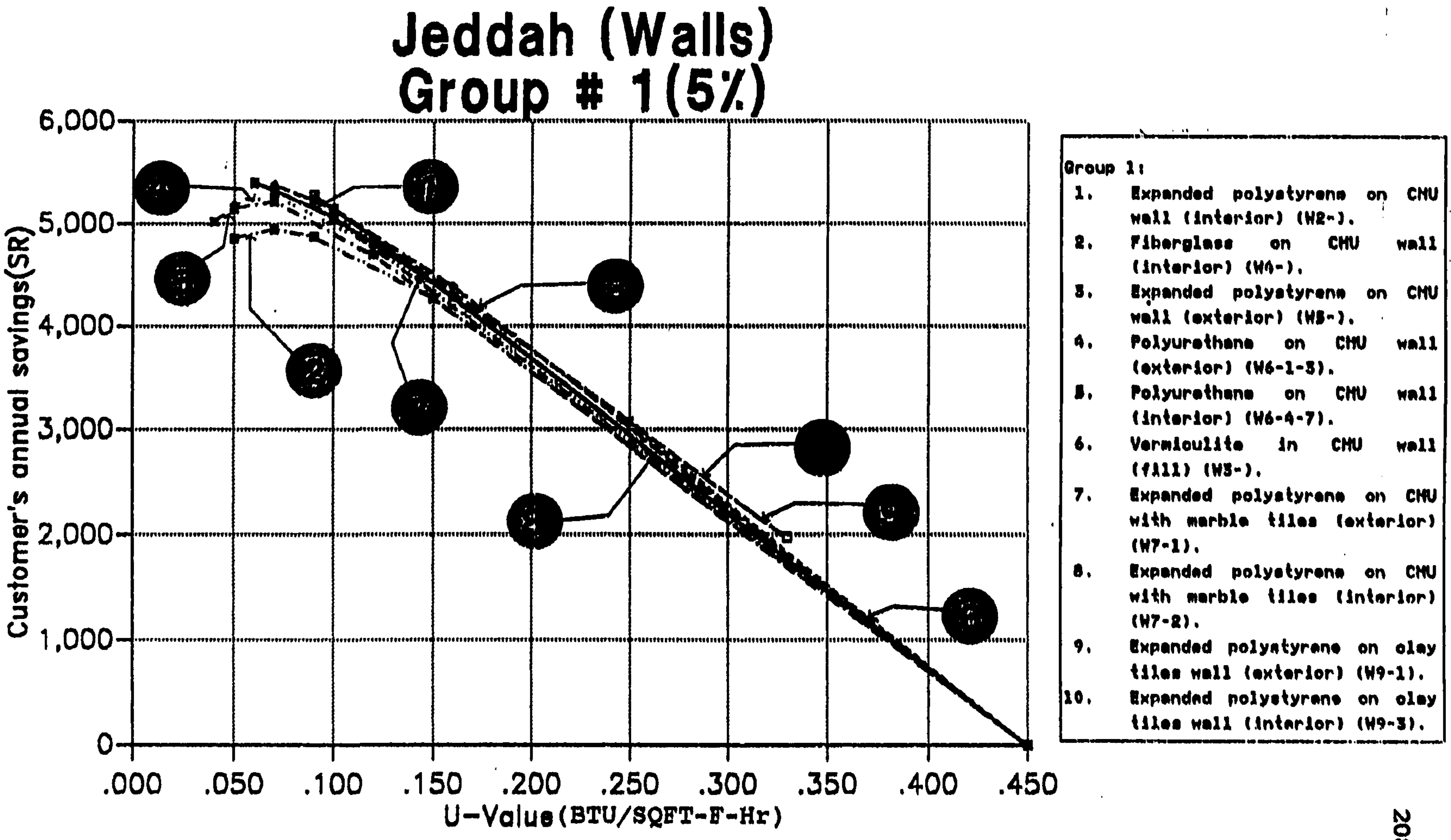


__Figure 7.9__: Jeddah - Walls # 1 (Thermal performance at 5%)

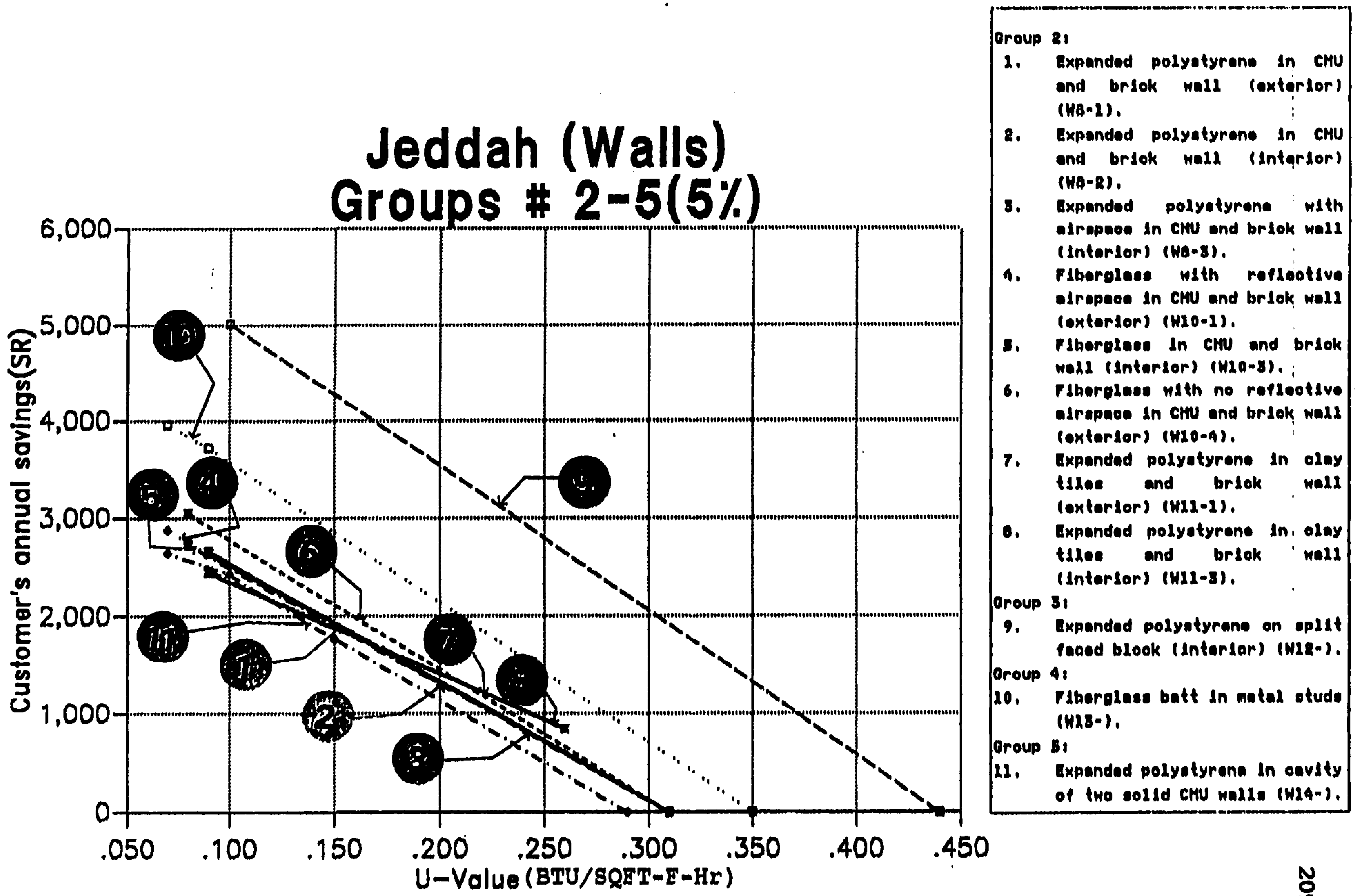
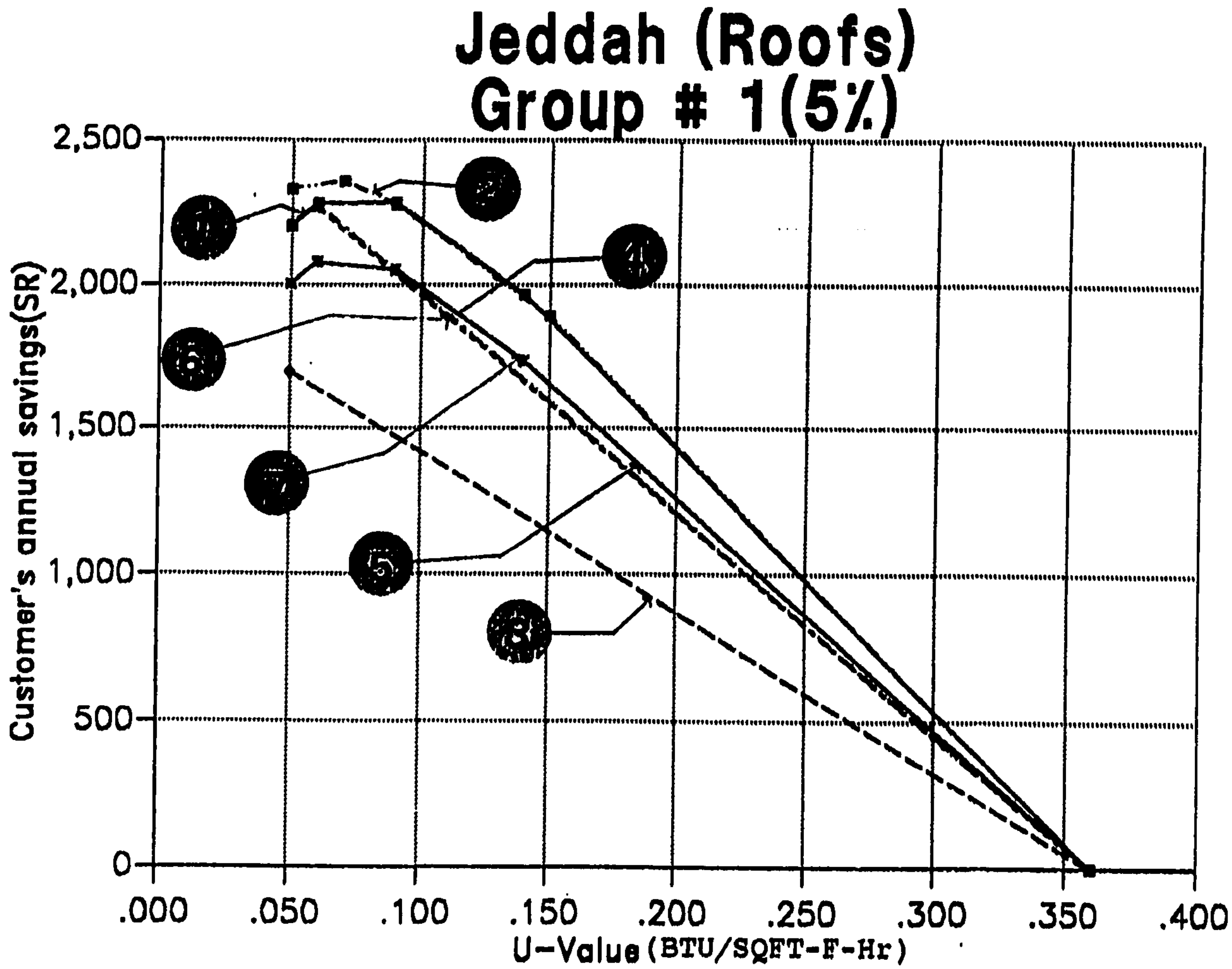


Figure 7.10: Jeddah - Walls # 2-5 (Thermal performance at 5%)



Group 1:

1. Extruded polystyrene on reinforced concrete roof (exterior) (R2-1-4).
2. Expanded polystyrene on reinforced concrete roof (exterior) (R2-5-8).
3. Polyurethane on reinforced concrete roof (exterior) (R3-1).
4. Extruded polystyrene on inverted reinforced concrete roof (exterior) (R4-1).
5. Extruded polystyrene on inverted reinforced concrete roof without mortar (exterior) (R4-2).
6. Extruded polystyrene on inverted reinforced concrete roof without mortar and sand (exterior) (R4-3).
7. Extruded polystyrene on reinforced concrete roof (interior) (R5-).

__Figure 7.11__: Jeddah - Roofs # 1 (Thermal performance at 5%)

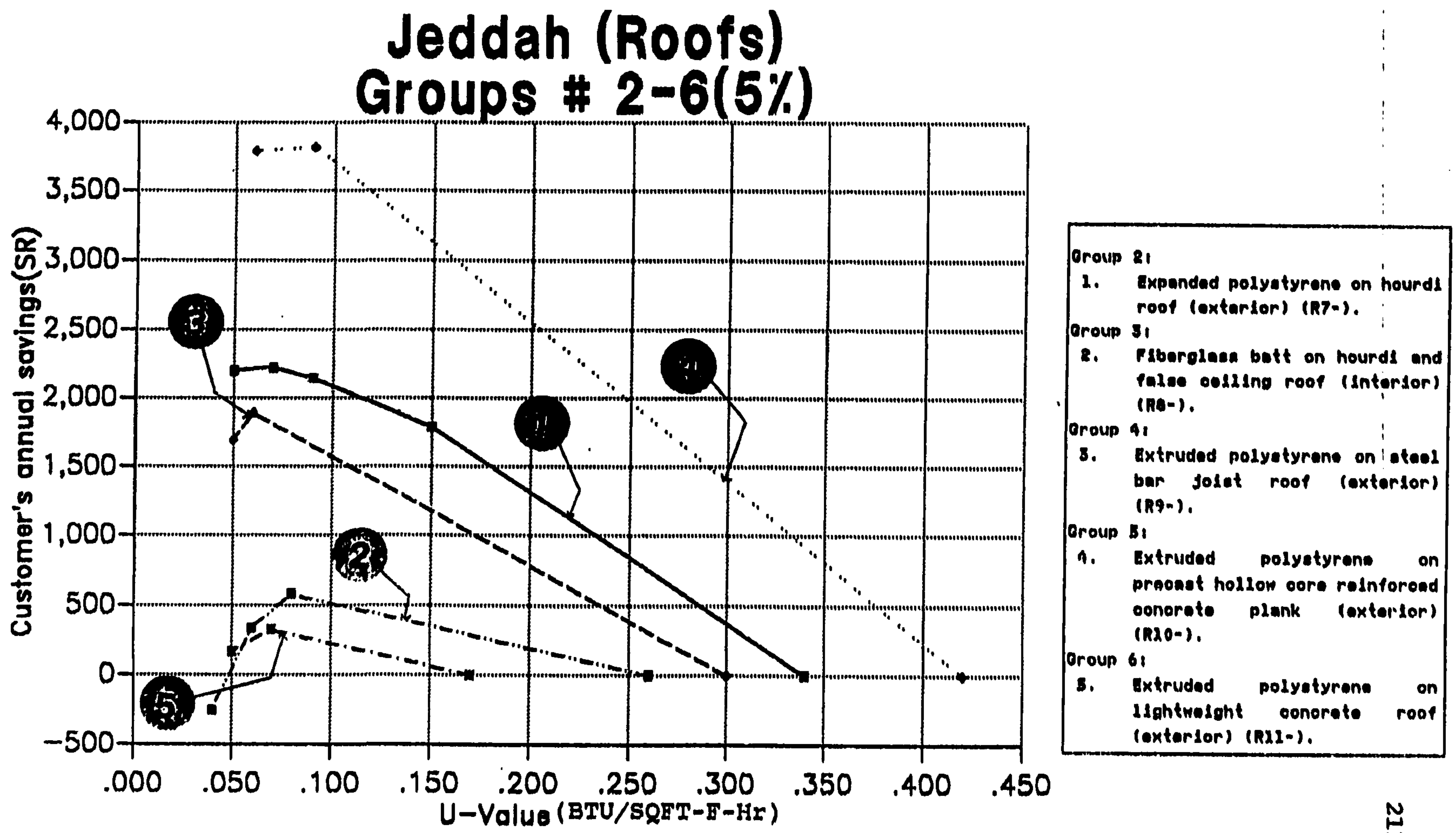


Figure 7.12: Jeddah - Roofs # 2-6 (Thermal performance at 5%)

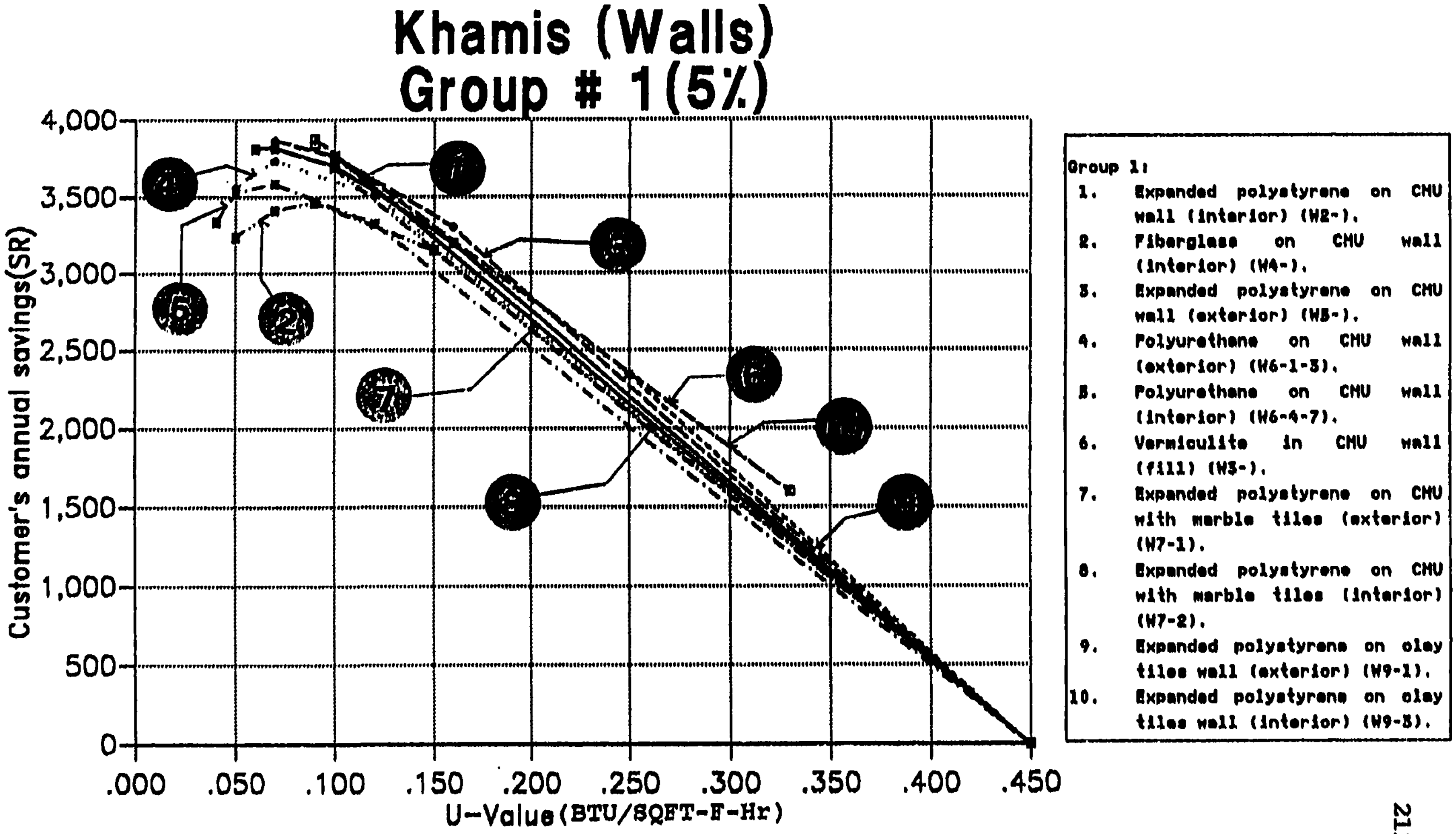
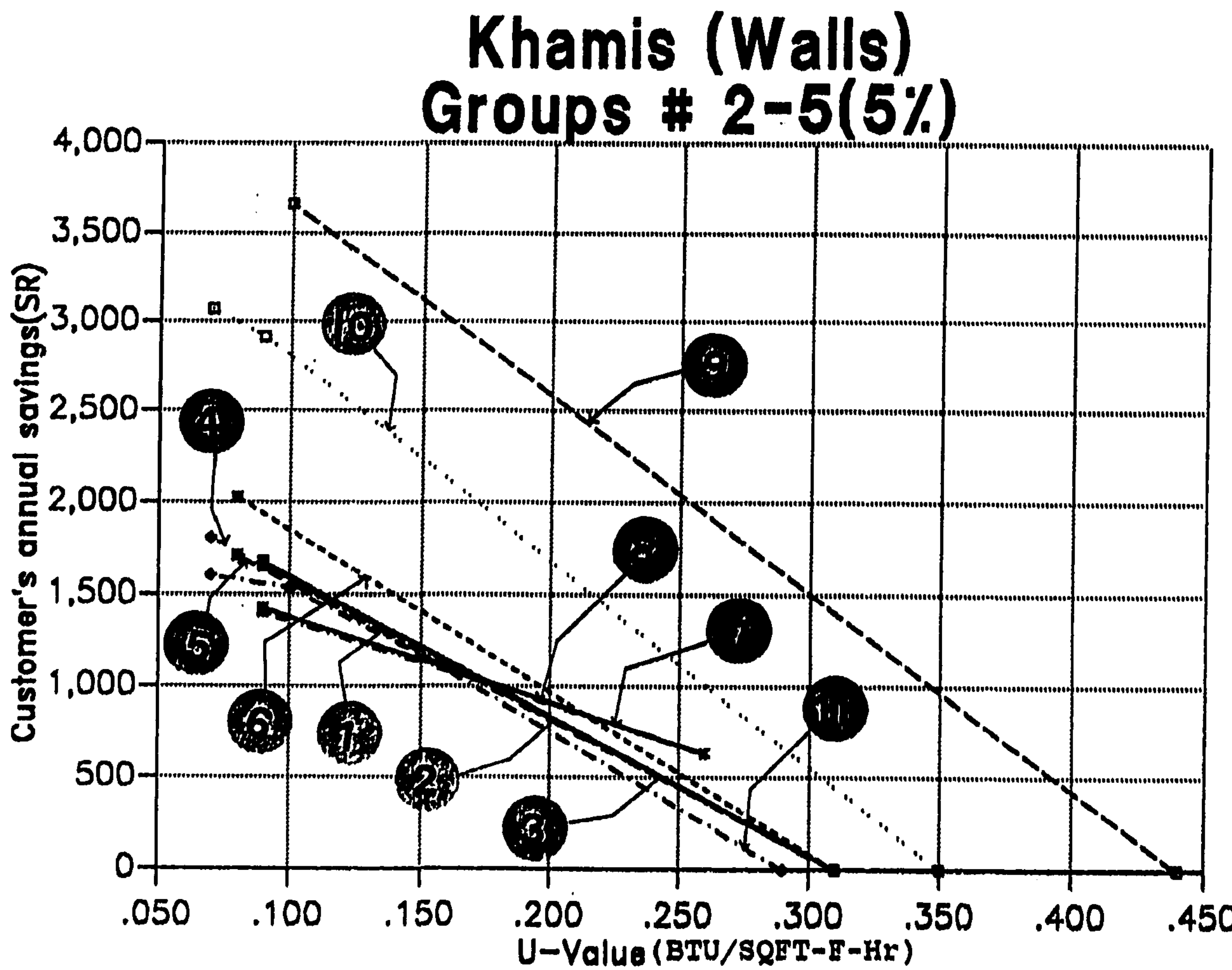


Figure 7.13: Khamis - Walls # 1 (Thermal performance at 5%)



Group 2:

1. Expanded polystyrene in CMU and brick wall (exterior) (W8-1).
2. Expanded polystyrene in CMU and brick wall (interior) (W8-2).
3. Expanded polystyrene with airspace in CMU and brick wall (interior) (W8-3).
4. Fiberglass with reflective airspace in CMU and brick wall (exterior) (W10-1).
5. Fiberglass in CMU and brick wall (interior) (W10-3).
6. Fiberglass with no reflective airspace in CMU and brick wall (exterior) (W10-4).
7. Expanded polystyrene in clay tiles and brick wall (exterior) (W11-1).
8. Expanded polystyrene in clay tiles and brick wall (interior) (W11-3).

Group 3:

9. Expanded polystyrene on split faced block (interior) (W12-).

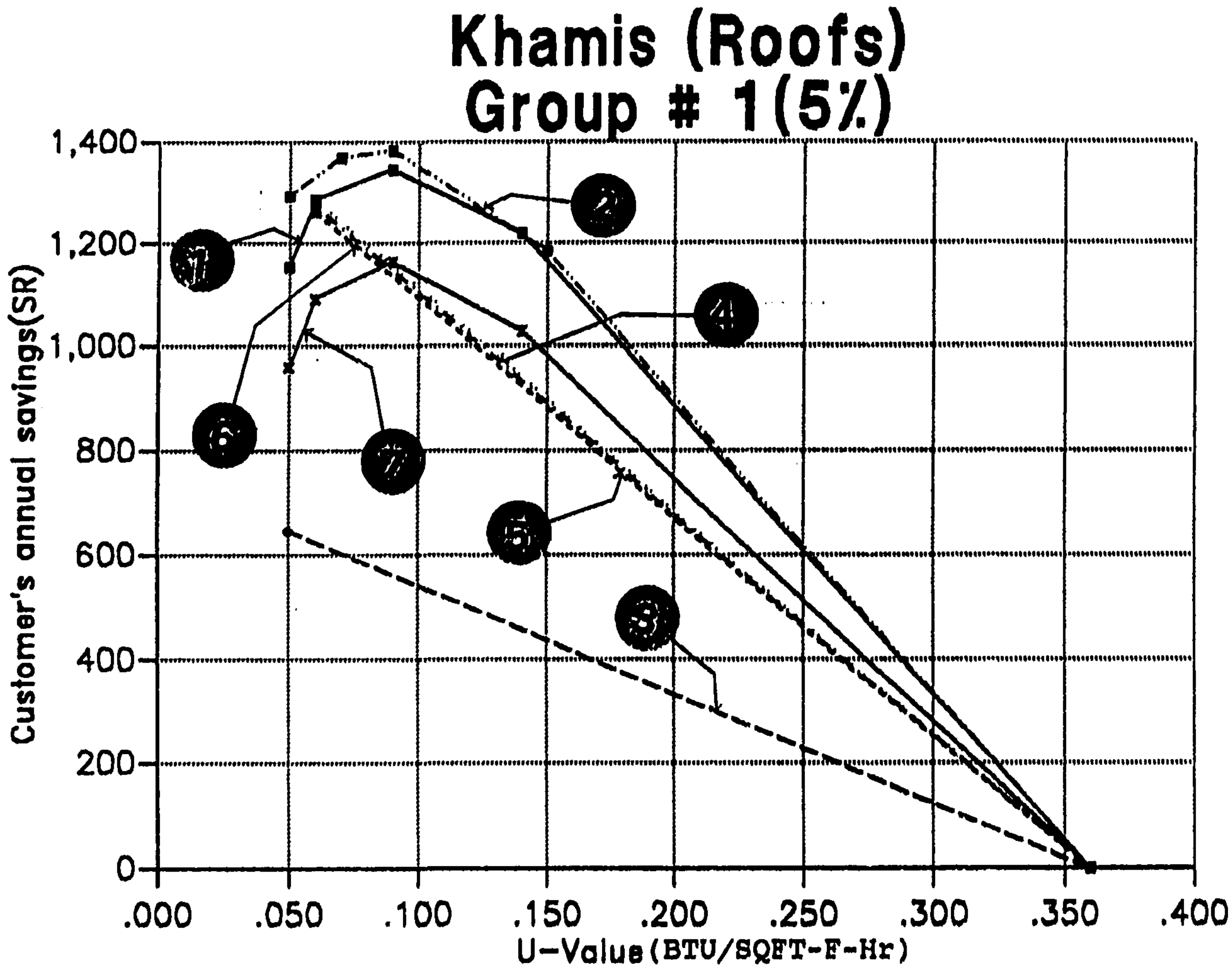
Group 4:

10. Fiberglass batt in metal studs (W13-).

Group 5:

11. Expanded polystyrene in cavity of two solid CMU walls (W14-).

Figure 7.14: Khamis - Walls # 2-5 (Thermal performance at 5%)



Group 1:

1. Extruded polystyrene on reinforced concrete roof (exterior) (R2-1-4).
2. Expanded polystyrene on reinforced concrete roof (exterior) (R2-5-6).
3. Polyurethane on reinforced concrete roof (exterior) (R3-1).
4. Extruded polystyrene on inverted reinforced concrete roof (exterior) (R4-1).
5. Extruded polystyrene on inverted reinforced concrete roof without mortar (exterior) (R4-2).
6. Extruded polystyrene on inverted reinforced concrete roof without mortar and sand (exterior) (R4-3).
7. Extruded polystyrene on reinforced concrete roof (interior) (R5-).

Figure 7.15: Khamis - Roofs # 1 (Thermal performance at 5%)

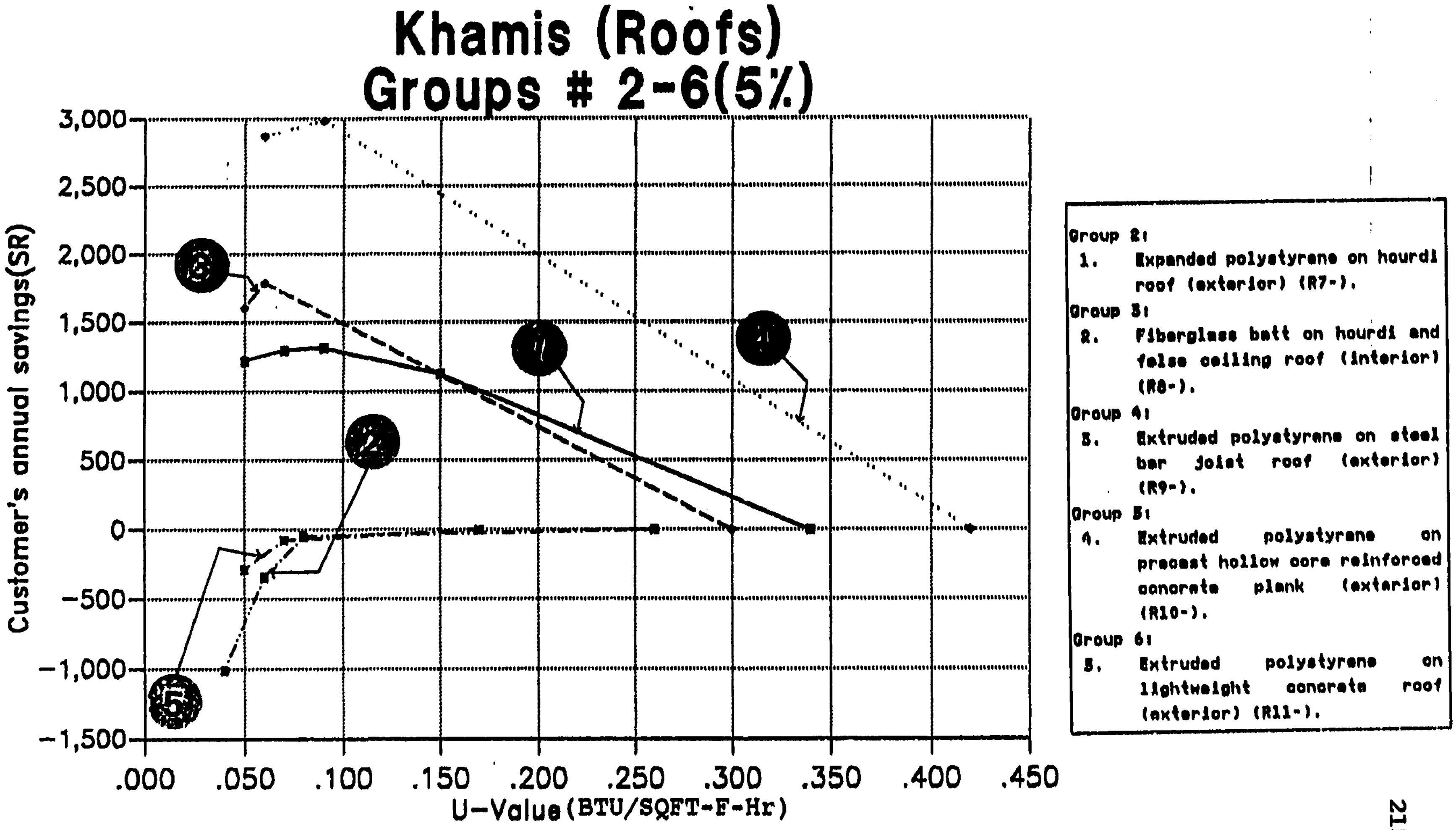


Figure 7.16: Khamis - Roofs # 2-6 (Thermal performance at 5%)

7.3 15% Discount rate

A discount rate of 15% was selected to see the effect of a greater than 10% discount rate on the thermal performance of the thermal insulation materials.

Figures 6.17 through 6.32 represent the thermal performance of each material within its group (walls and roofs) versus the customer's annual savings at a discount rate of 15%.

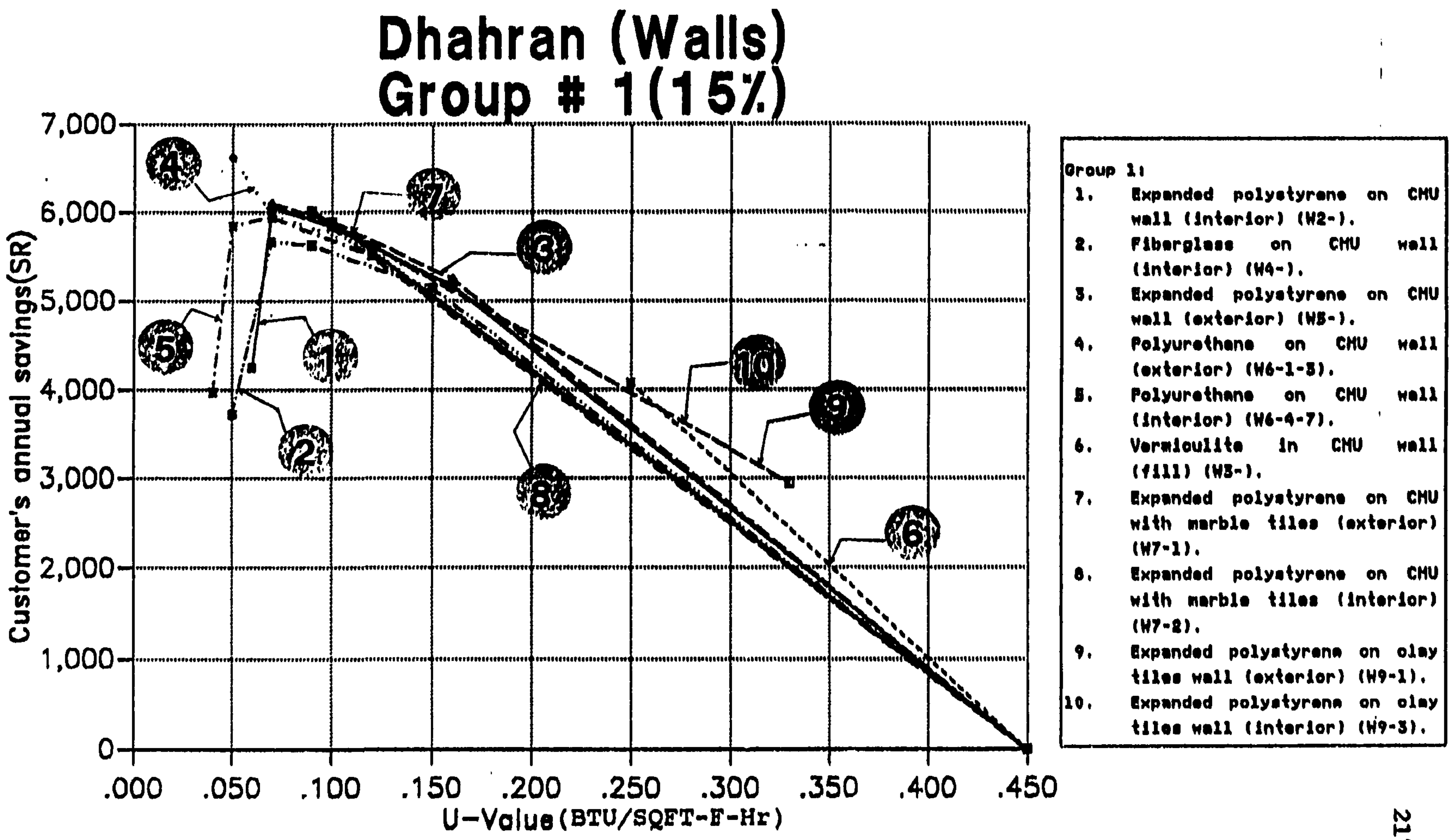
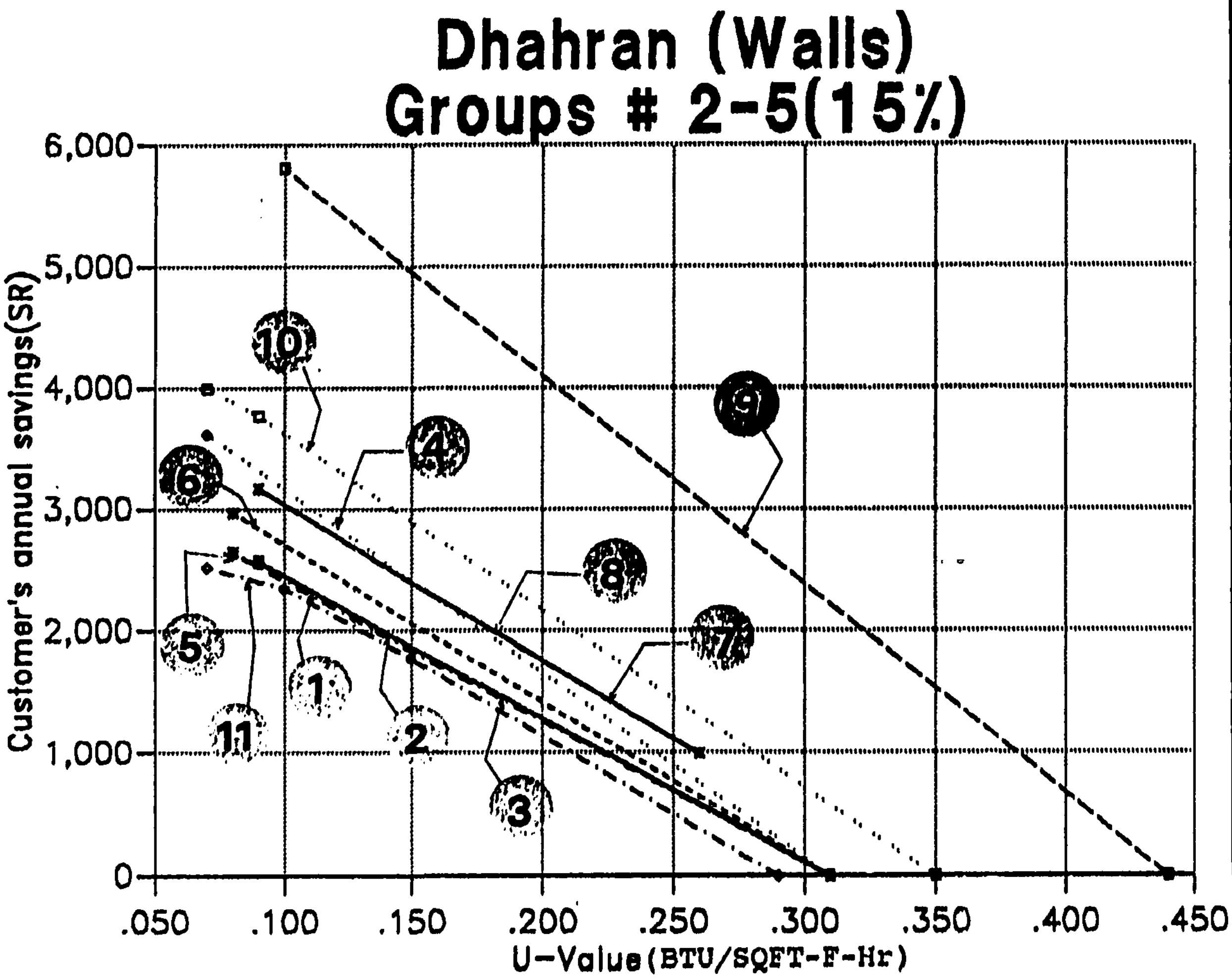


Figure 7.17: Dhahran - Walls # 1 (Thermal performance at 15%)



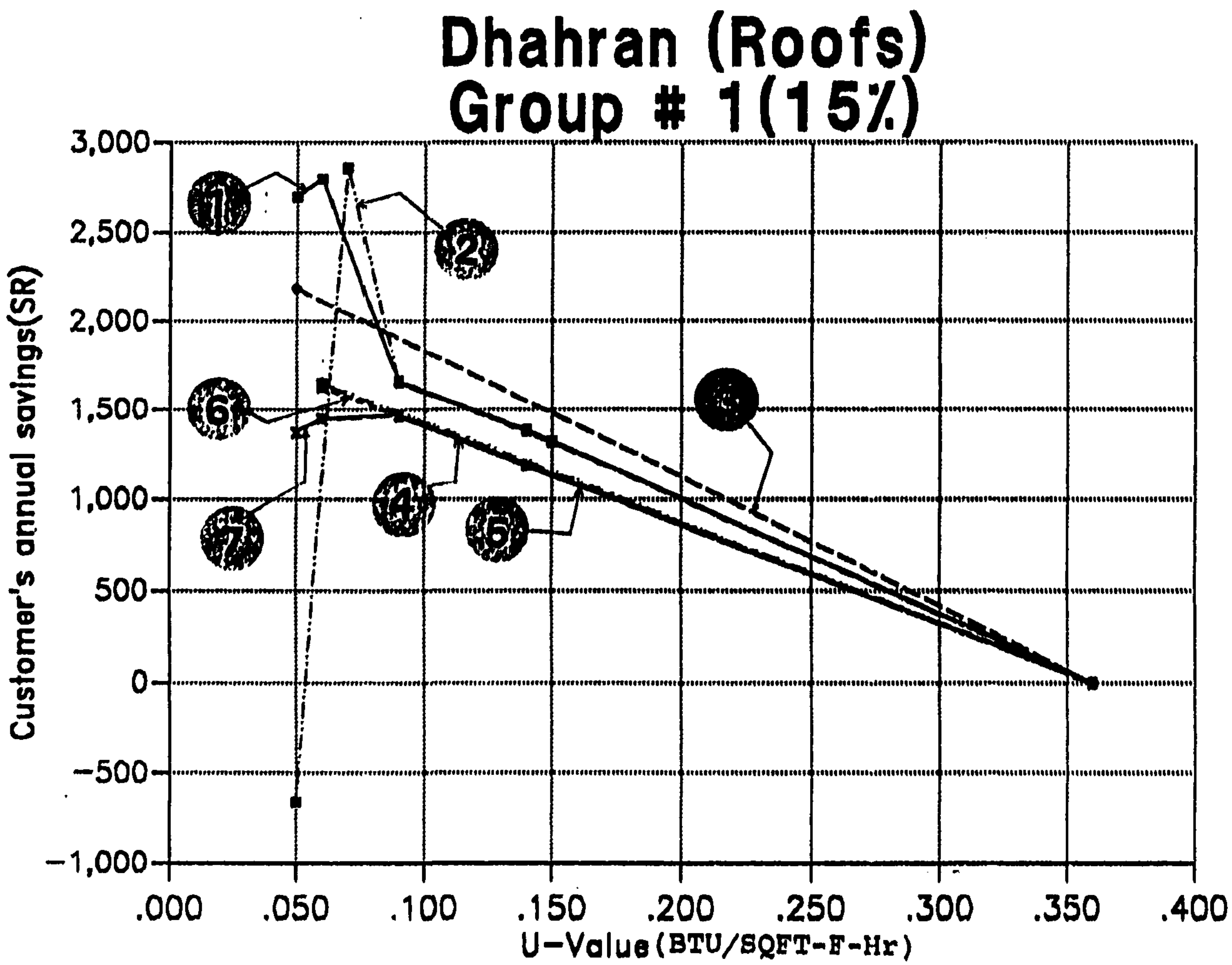
Group 2:
1. Expanded polystyrene in CMU and brick wall (exterior) (W8-1).
2. Expanded polystyrene in CMU and brick wall (interior) (W8-2).
3. Expanded polystyrene with airspace in CMU and brick wall (interior) (W8-3).
4. Fiberglass with reflective airspace in CMU and brick wall (exterior) (W10-1).
5. Fiberglass in CMU and brick wall (interior) (W10-3).
6. Fiberglass with no reflective airspace in CMU and brick wall (exterior) (W10-4).
7. Expanded polystyrene in clay tiles and brick wall (exterior) (W11-1).
8. Expanded polystyrene in clay tiles and brick wall (interior) (W11-3).

Group 3:
9. Expanded polystyrene on split faced block (interior) (W12-).

Group 4:
10. Fiberglass batt in metal studs (W13-).

Group 5:
11. Expanded polystyrene in cavity of two solid CMU walls (W14-).

Figure 7.18: Dhahran - Walls # 2-5 (Thermal performance at 15%)



Group 1:

1. Extruded polystyrene on reinforced concrete roof (exterior) (R2-1-4).
2. Expanded polystyrene on reinforced concrete roof (exterior) (R2-5-8).
3. Polyurethane on reinforced concrete roof (exterior) (R3-1).
4. Extruded polystyrene on inverted reinforced concrete roof (exterior) (R4-1).
5. Extruded polystyrene on inverted reinforced concrete roof without mortar (exterior) (R4-2).
6. Extruded polystyrene on inverted reinforced concrete roof without mortar and sand (exterior) (R4-3).
7. Extruded polystyrene on reinforced concrete roof (interior) (R5-).

Figure 7.19: Dhahran - Roofs # 1 (Thermal performance at 15%)

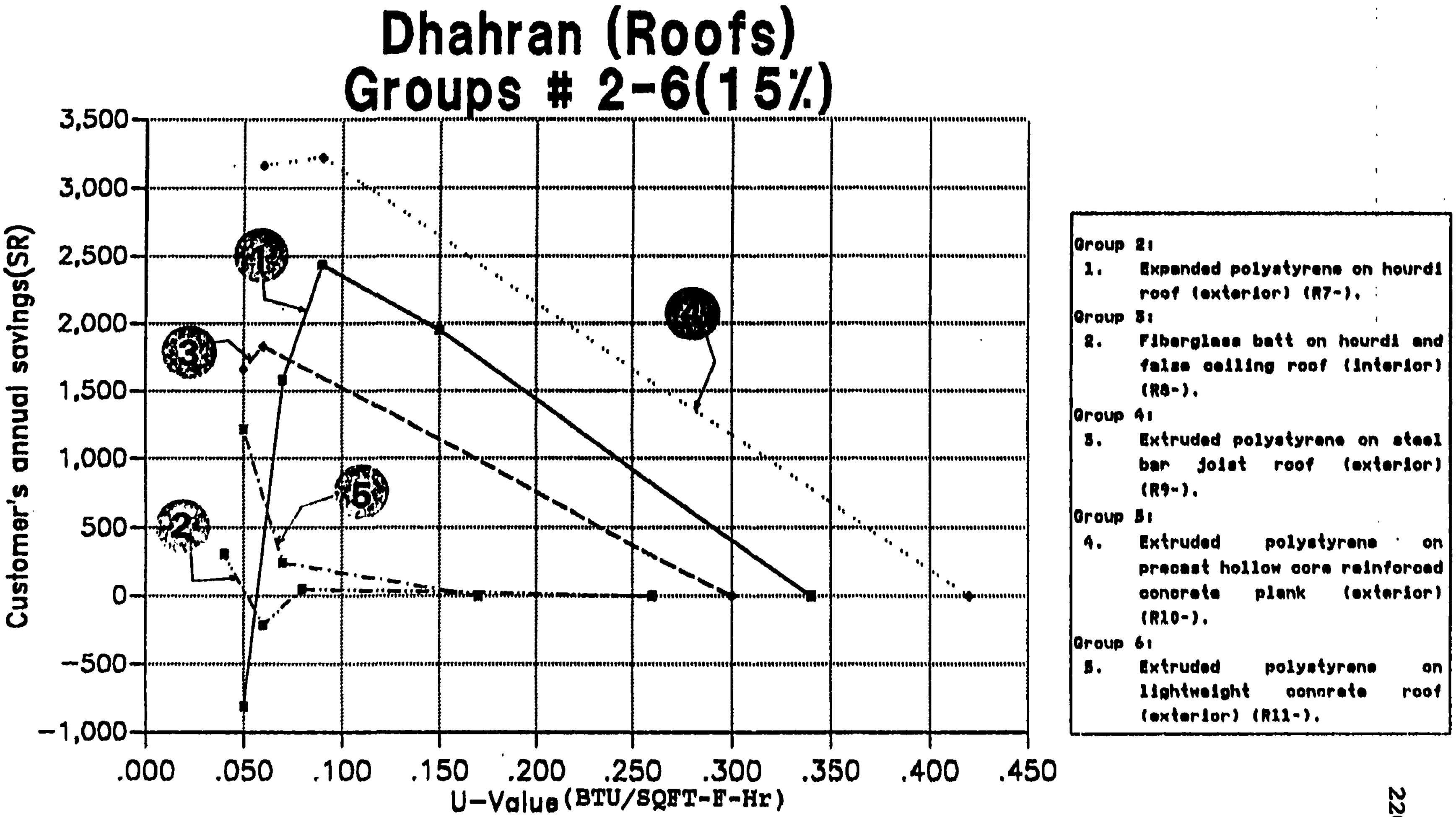


Figure 7.20: Dhahran - Roofs # 2-6 (Thermal performance at 15%)

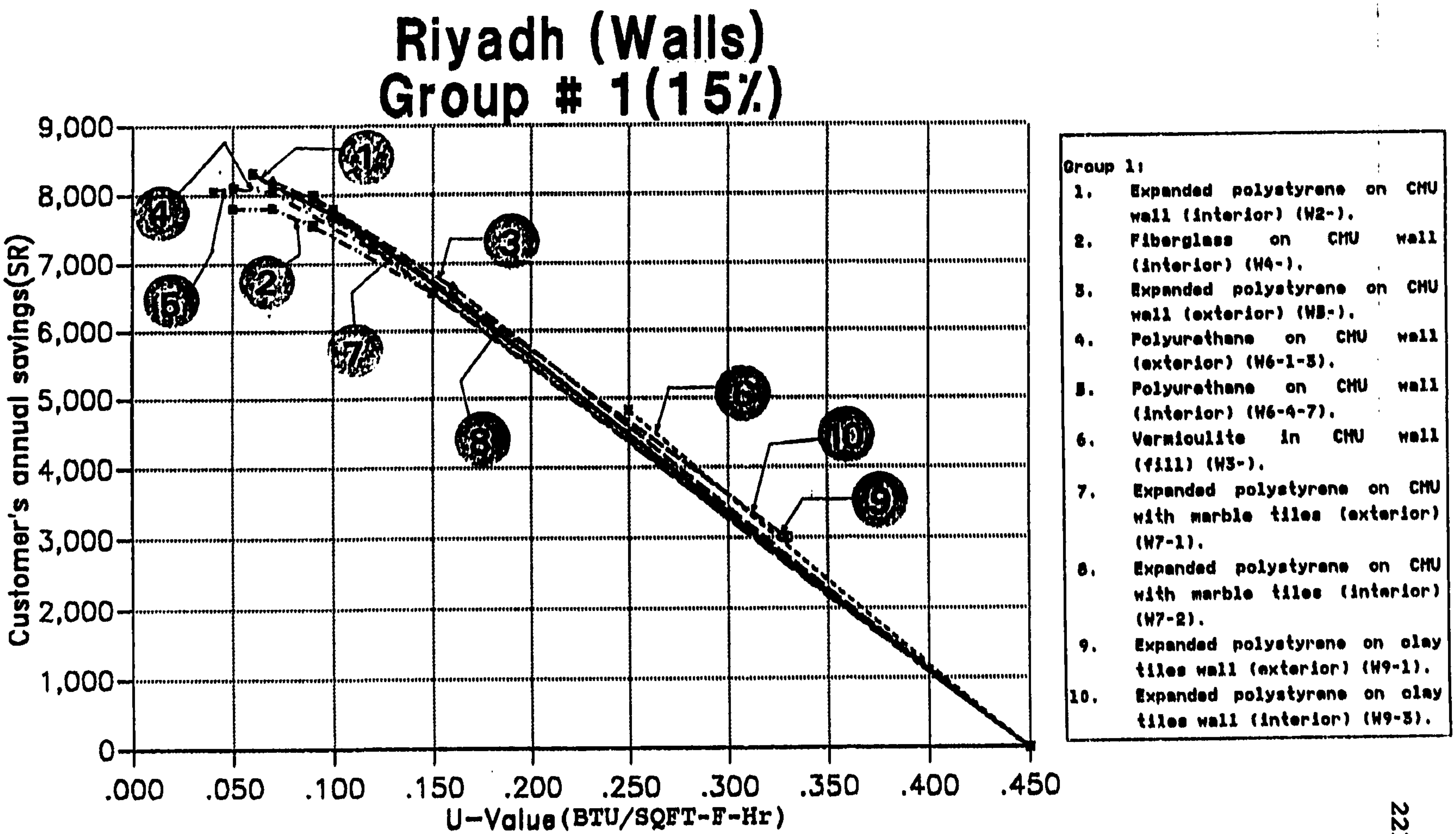
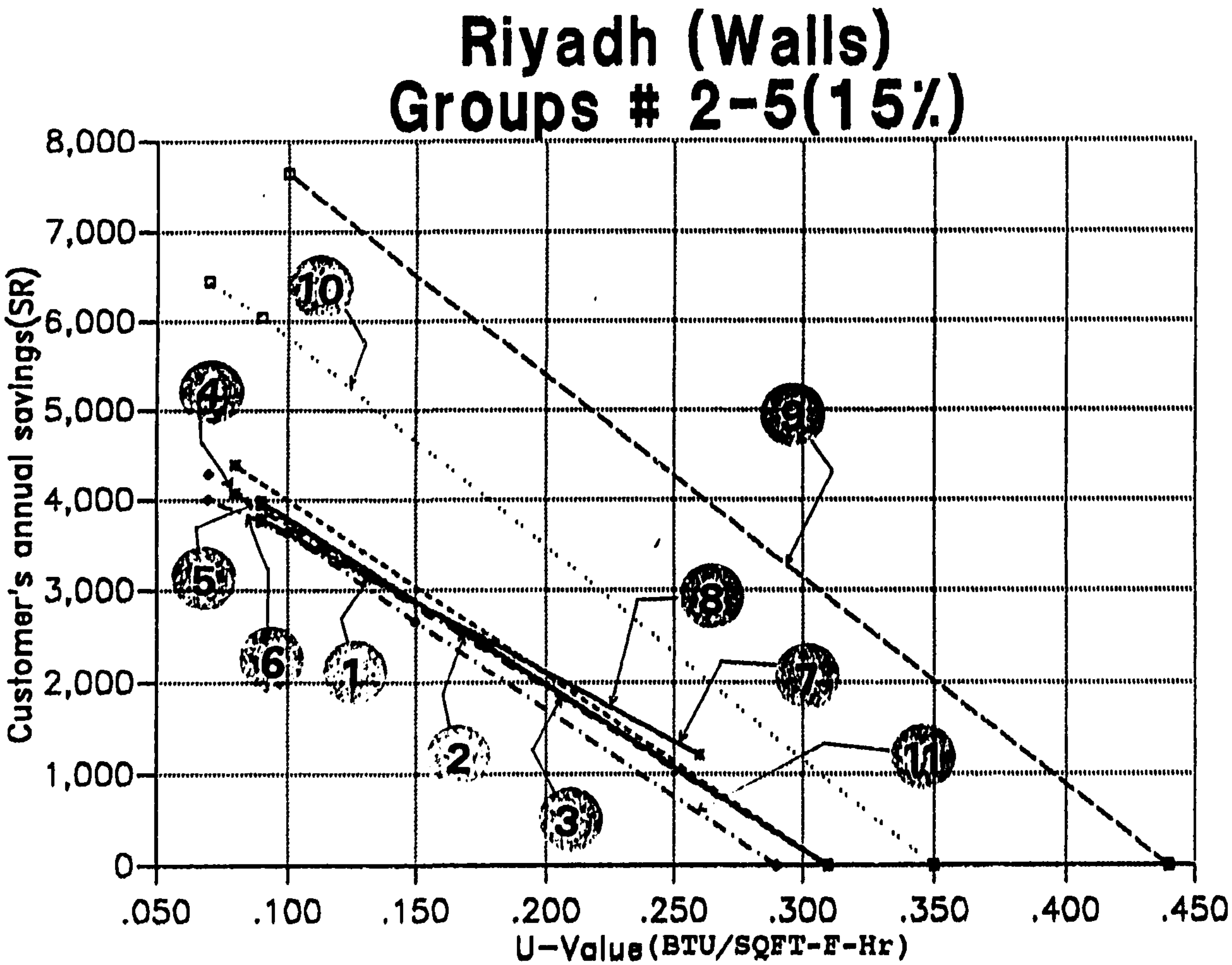


__Figure 7.21__: Riyadh - Walls # 1 (Thermal performance at 15%)



Group 2:

1. Expanded polystyrene in CMU and brick wall (exterior) (W8-1).
2. Expanded polystyrene in CMU and brick wall (interior) (W8-2).
3. Expanded polystyrene with airspace in CMU and brick wall (interior) (W8-3).
4. Fiberglass with reflective airspace in CMU and brick wall (exterior) (W10-1).
5. Fiberglass in CMU and brick wall (interior) (W10-3).
6. Fiberglass with no reflective airspace in CMU and brick wall (exterior) (W10-4).
7. Expanded polystyrene in clay tiles and brick wall (exterior) (W11-1).
8. Expanded polystyrene in clay tiles and brick wall (interior) (W11-3).

Group 3:

9. Expanded polystyrene on split faced block (interior) (W12-).

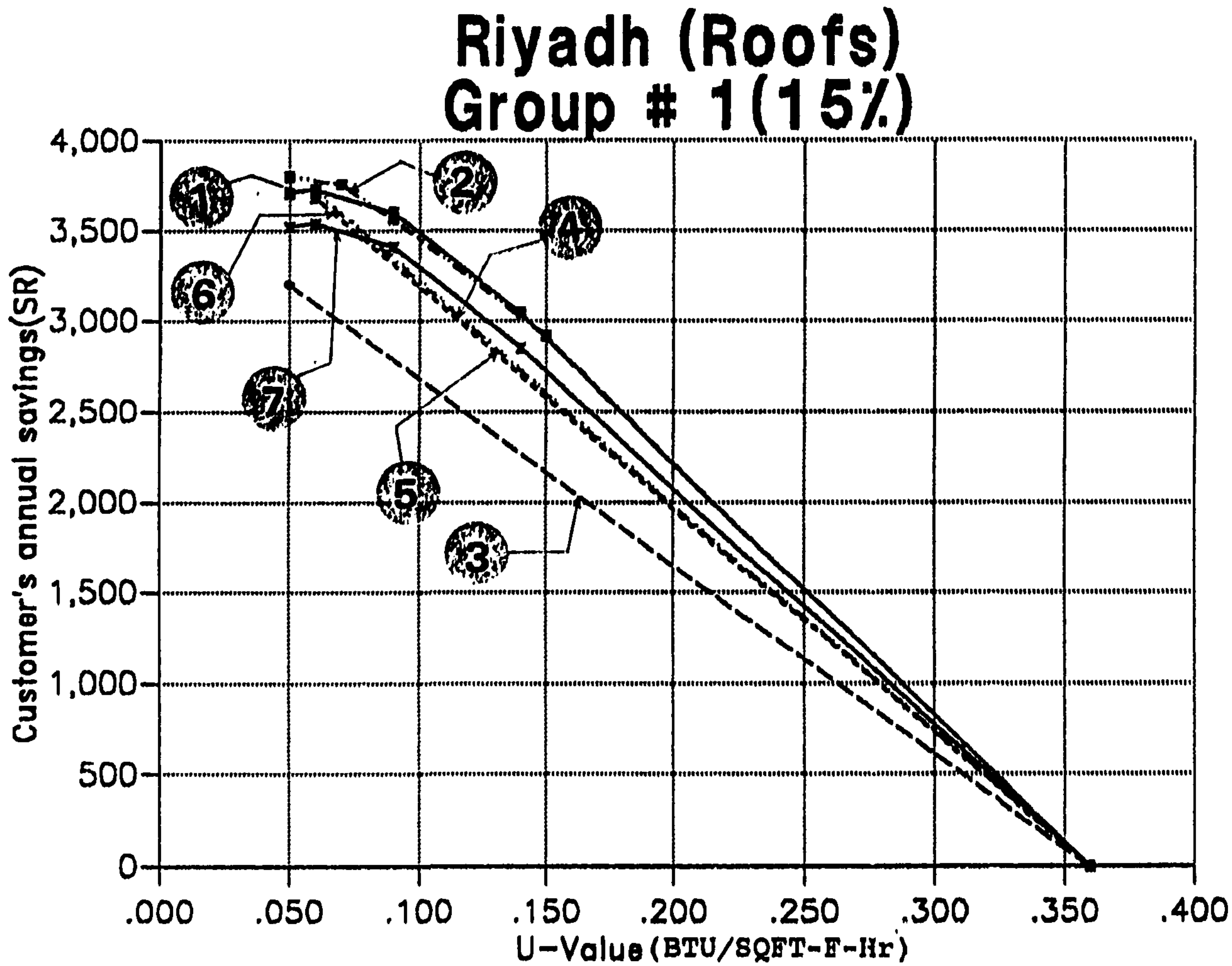
Group 4:

10. Fiberglass batt in metal studs (W13-).

Group 5:

11. Expanded polystyrene in cavity of two solid CMU walls (W14-).

Figure 7.22: Riyadh - Walls # 2-5 (Thermal performance at 15%)



Group 1:

1. Extruded polystyrene on reinforced concrete roof (exterior) (R2-1-4).
2. Expanded polystyrene on reinforced concrete roof (exterior) (R2-5-8).
3. Polyurethane on reinforced concrete roof (exterior) (R3-1).
4. Extruded polystyrene on inverted reinforced concrete roof (exterior) (R4-1).
5. Extruded polystyrene on inverted reinforced concrete roof without mortar (exterior) (R4-2).
6. Extruded polystyrene on inverted reinforced concrete roof without mortar and sand (exterior) (R4-3).
7. Extruded polystyrene on reinforced concrete roof (interior) (R5-).

__Figure 7.23__: Riyadh - Roofs # 1 (Thermal performance at 15%)

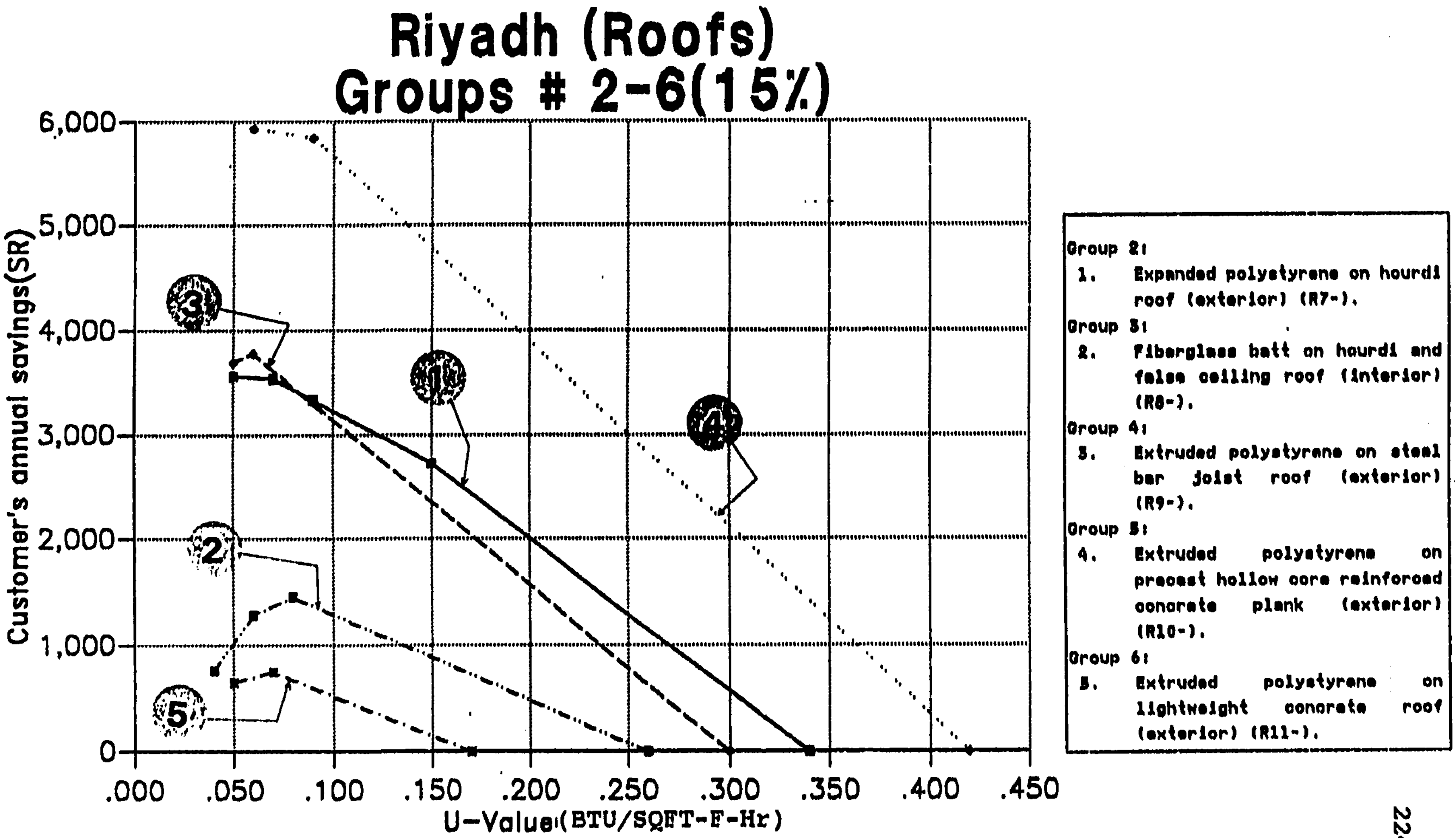


__Figure 7.24__: Riyadh - Roofs # 2-6 (Thermal performance at 15%)

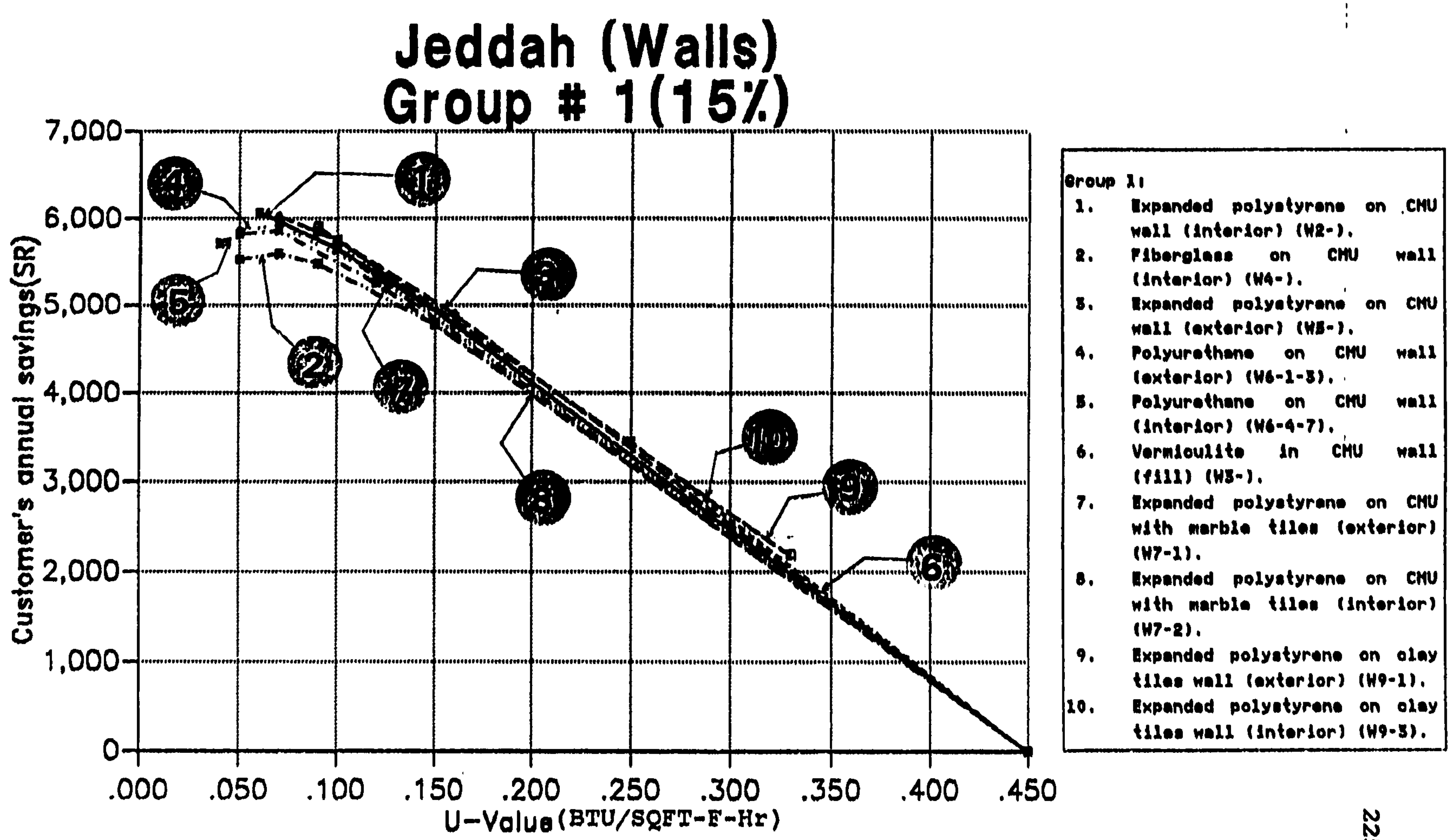
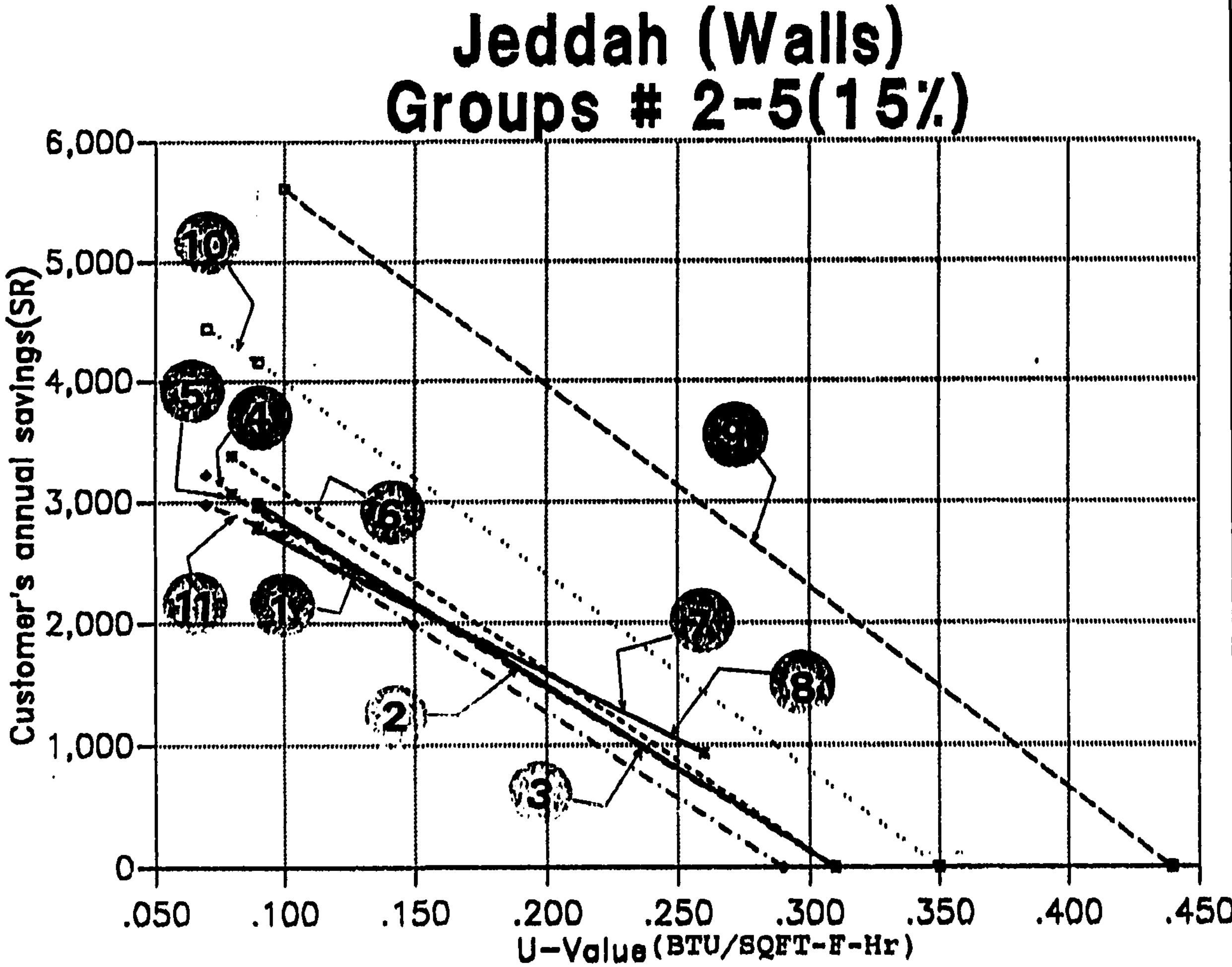


Figure 7.25: Jeddah - Walls # 1 (Thermal performance at 15%)



Group 2:

1. Expanded polystyrene in CMU and brick wall (exterior) (W8-1).
2. Expanded polystyrene in CMU and brick wall (interior) (W8-2).
3. Expanded polystyrene with airspace in CMU and brick wall (interior) (W8-3).
4. Fiberglass with reflective airspace in CMU and brick wall (exterior) (W10-1).
5. Fiberglass in CMU and brick wall (interior) (W10-3).
6. Fiberglass with no reflective airspace in CMU and brick wall (exterior) (W10-4).
7. Expanded polystyrene in clay tiles and brick wall (exterior) (W11-1).
8. Expanded polystyrene in clay tiles and brick wall (interior) (W11-3).

Group 3:

9. Expanded polystyrene on split faced block (interior) (W12-).

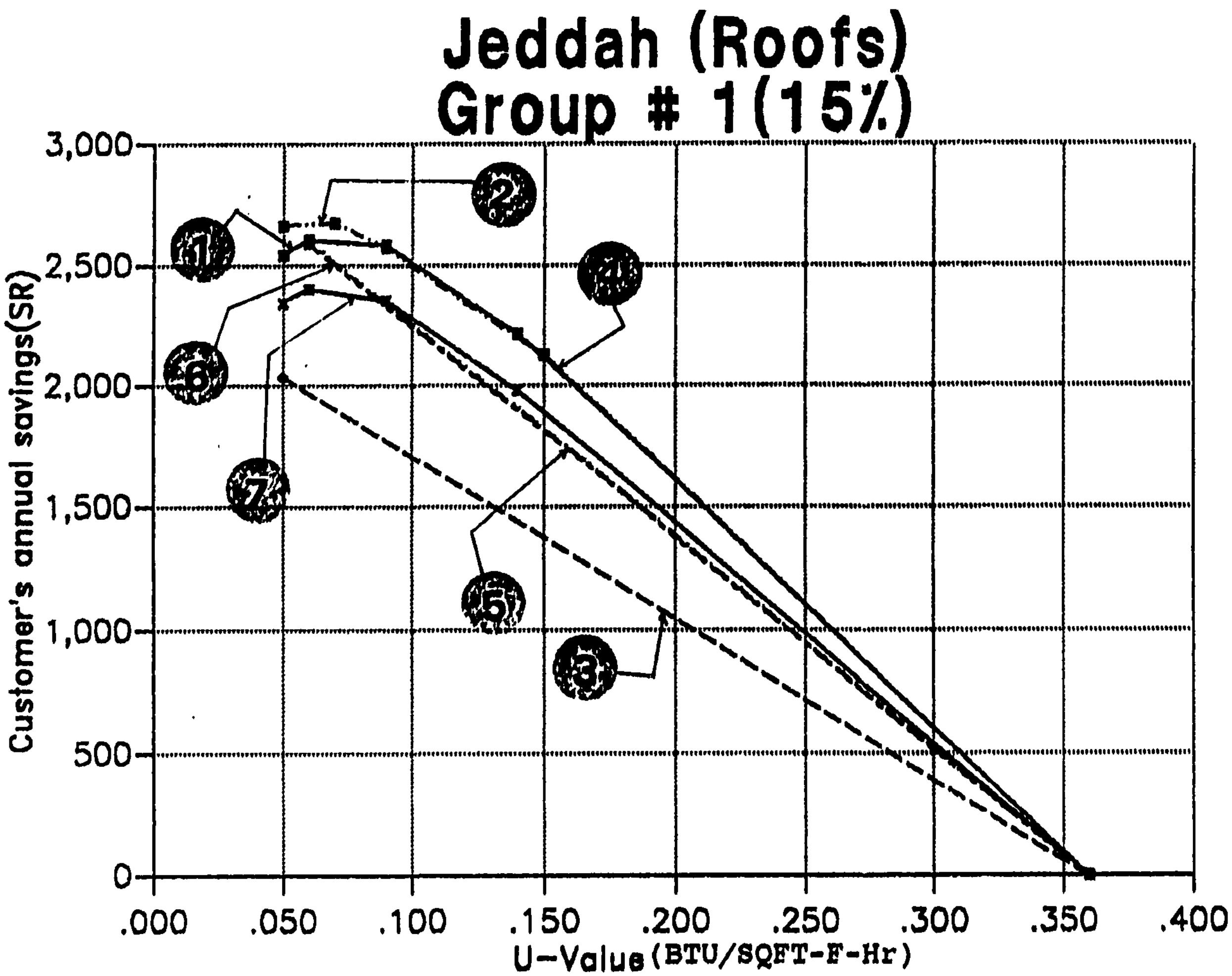
Group 4:

10. Fiberglass batt in metal studs (W13-).

Group 5:

11. Expanded polystyrene in cavity of two solid CMU walls (W14-).

Figure 7.26: Jeddah - Walls # 2-5 (Thermal performance at 15%)



Group 1:

1. Extruded polystyrene on reinforced concrete roof (exterior) (R2-1-4).
2. Expanded polystyrene on reinforced concrete roof (exterior) (R2-5-6).
3. Polyurethane on reinforced concrete roof (exterior) (R3-1).
4. Extruded polystyrene on inverted reinforced concrete roof (exterior) (R4-1).
5. Extruded polystyrene on inverted reinforced concrete roof without mortar (exterior) (R4-2).
6. Extruded polystyrene on inverted reinforced concrete roof without mortar and sand (exterior) (R4-3).
7. Extruded polystyrene on reinforced concrete roof (interior) (R5-).

Figure 7.27: Jeddah - Roofs # 1 (Thermal performance at 15%)

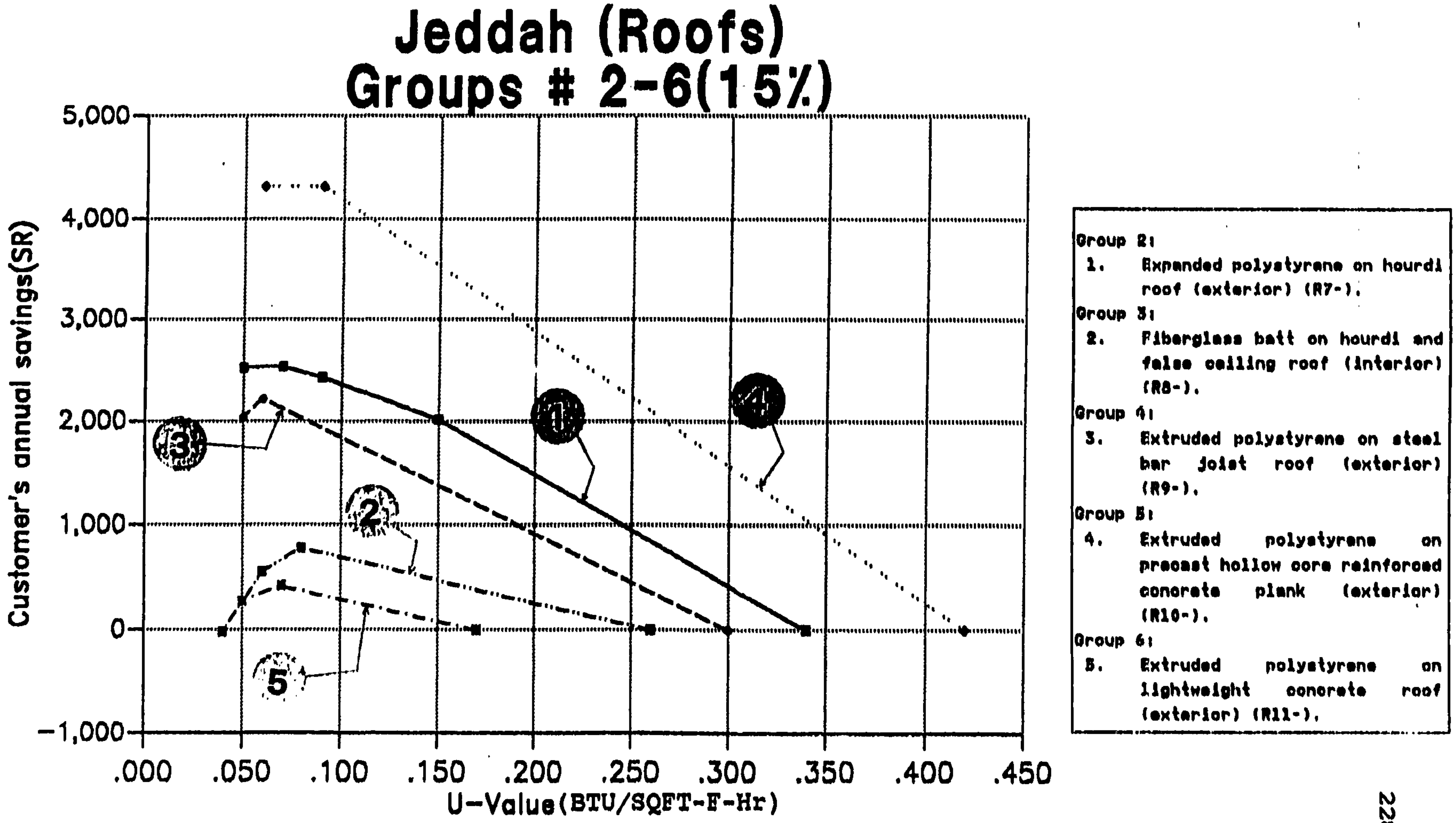
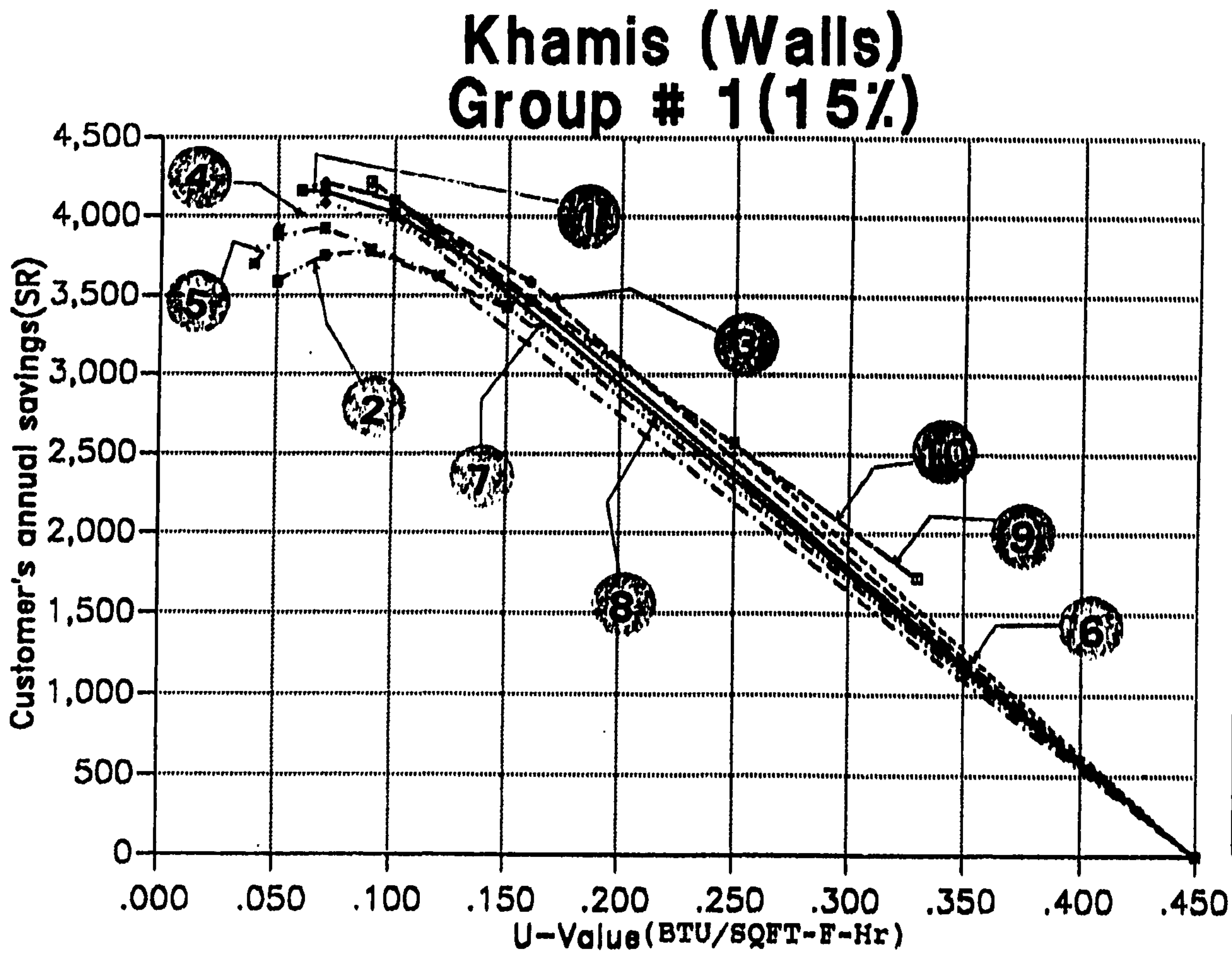
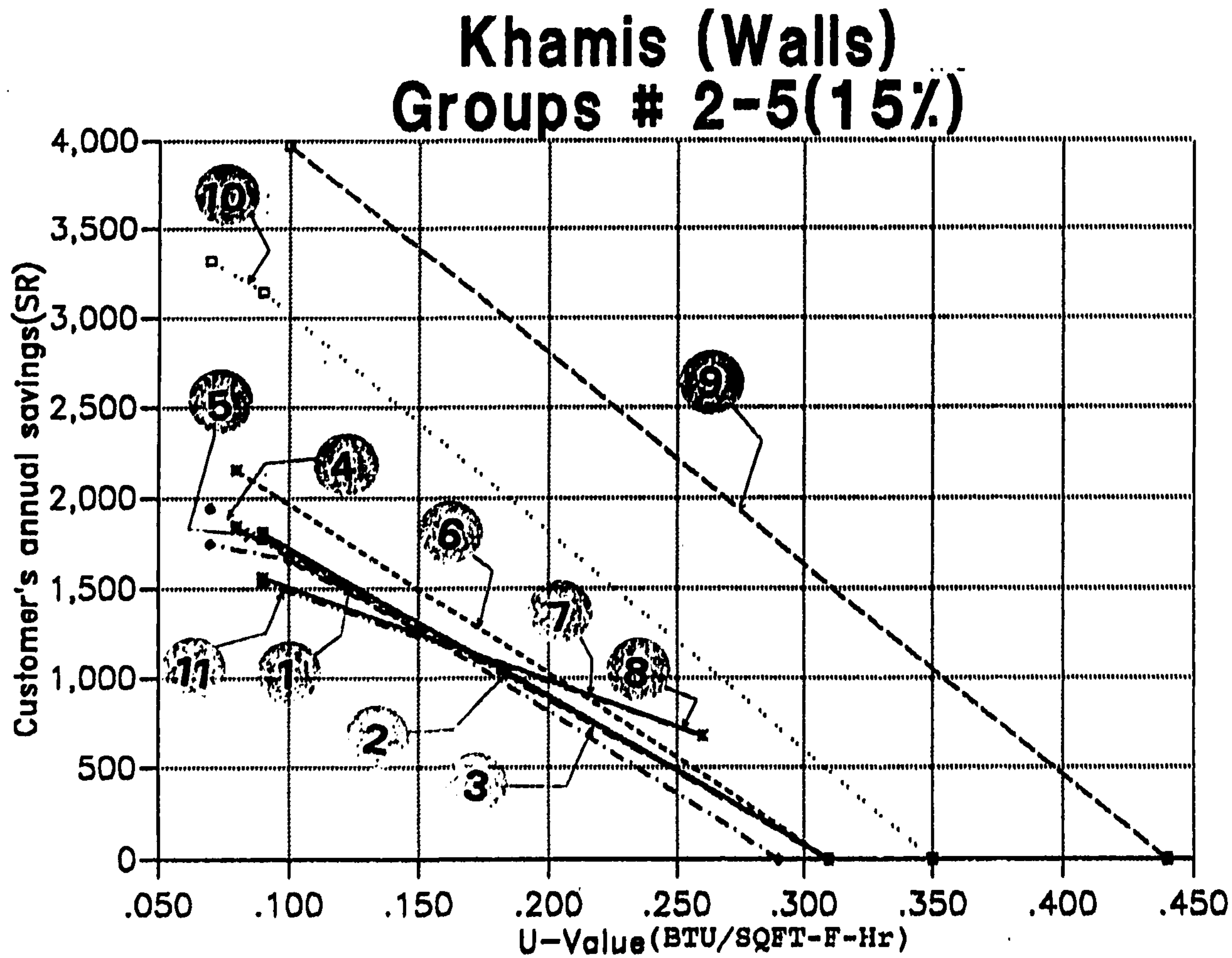


Figure 7.28: Jeddah - Roofs # 2-6 (Thermal performance at 15%)



Group 1:
1. Expanded polystyrene on CMU wall (interior) (W2-).
2. Fiberglass on CMU wall (interior) (W4-).
3. Expanded polystyrene on CMU wall (exterior) (W3-).
4. Polyurethane on CMU wall (exterior) (W6-1-3).
5. Polyurethane on CMU wall (interior) (W6-4-7).
6. Vermiculite in CMU wall (fill) (W5-).
7. Expanded polystyrene on CMU with marble tiles (exterior) (W7-1).
8. Expanded polystyrene on CMU with marble tiles (interior) (W7-2).
9. Expanded polystyrene on clay tiles wall (exterior) (W9-1).
10. Expanded polystyrene on clay tiles wall (interior) (W9-3).

__Figure 7.29__: Khamis - Walls # 1 (Thermal performance at 15%)



Group 2:
1. Expanded polystyrene in CMU and brick wall (exterior) (W8-1).
2. Expanded polystyrene in CMU and brick wall (interior) (W8-2).
3. Expanded polystyrene with airspace in CMU and brick wall (interior) (W8-3).
4. Fiberglass with reflective airspace in CMU and brick wall (exterior) (W10-1).
5. Fiberglass in CMU and brick wall (interior) (W10-3).
6. Fiberglass with no reflective airspace in CMU and brick wall (exterior) (W10-4).
7. Expanded polystyrene in clay tiles and brick wall (exterior) (W11-1).
8. Expanded polystyrene in clay tiles and brick wall (interior) (W11-3).

Group 3:
9. Expanded polystyrene on split faced block (interior) (W12-).

Group 4:
10. Fiberglass batt in metal studs (W13-).

Group 5:
11. Expanded polystyrene in cavity of two solid CMU walls (W14-).

Figure 7.30: Khamis - Walls # 2-5 (Thermal performance at 15%)

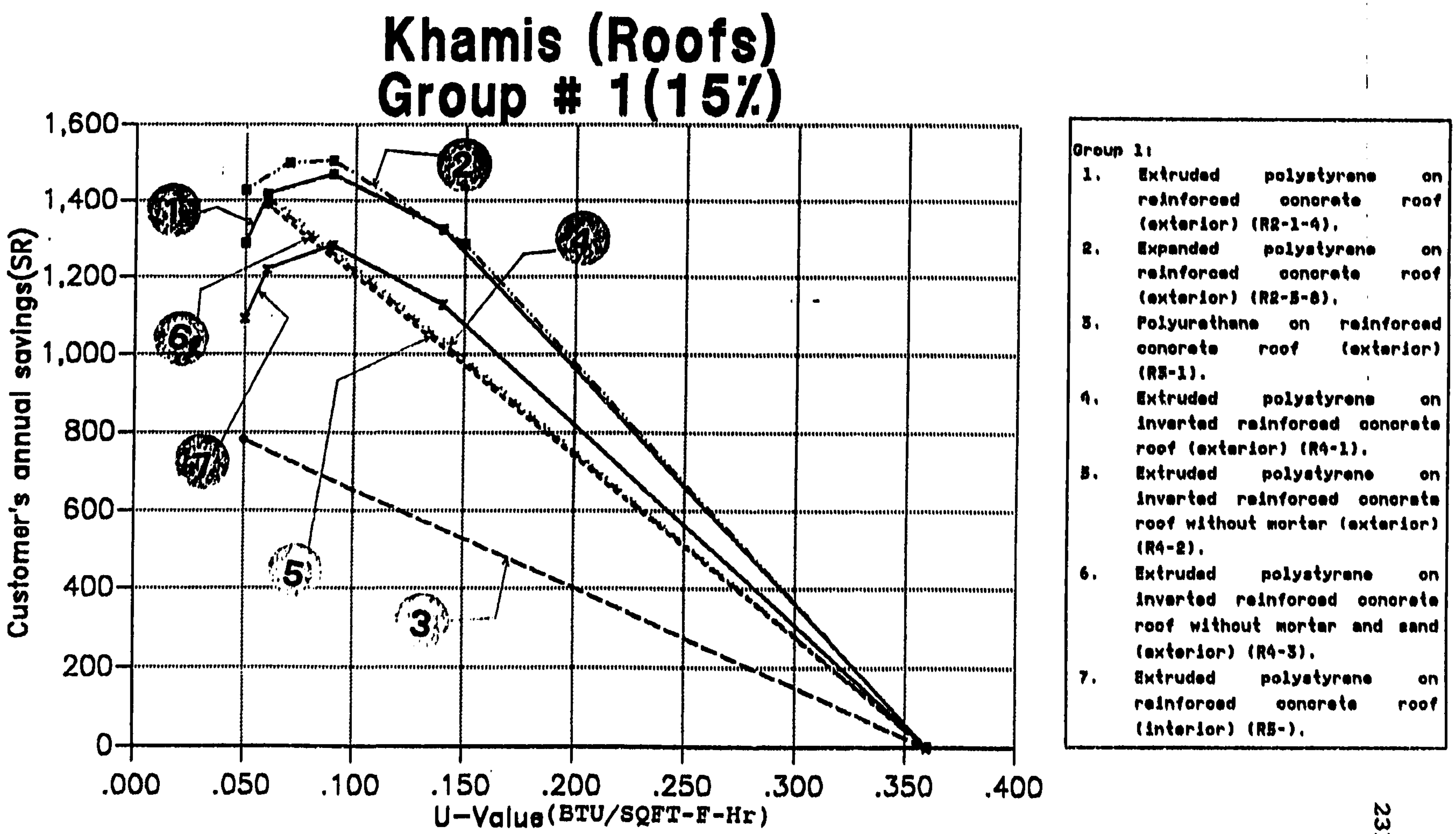


Figure 7.31: Khamis - Roofs # 1 (Thermal performance at 15%)

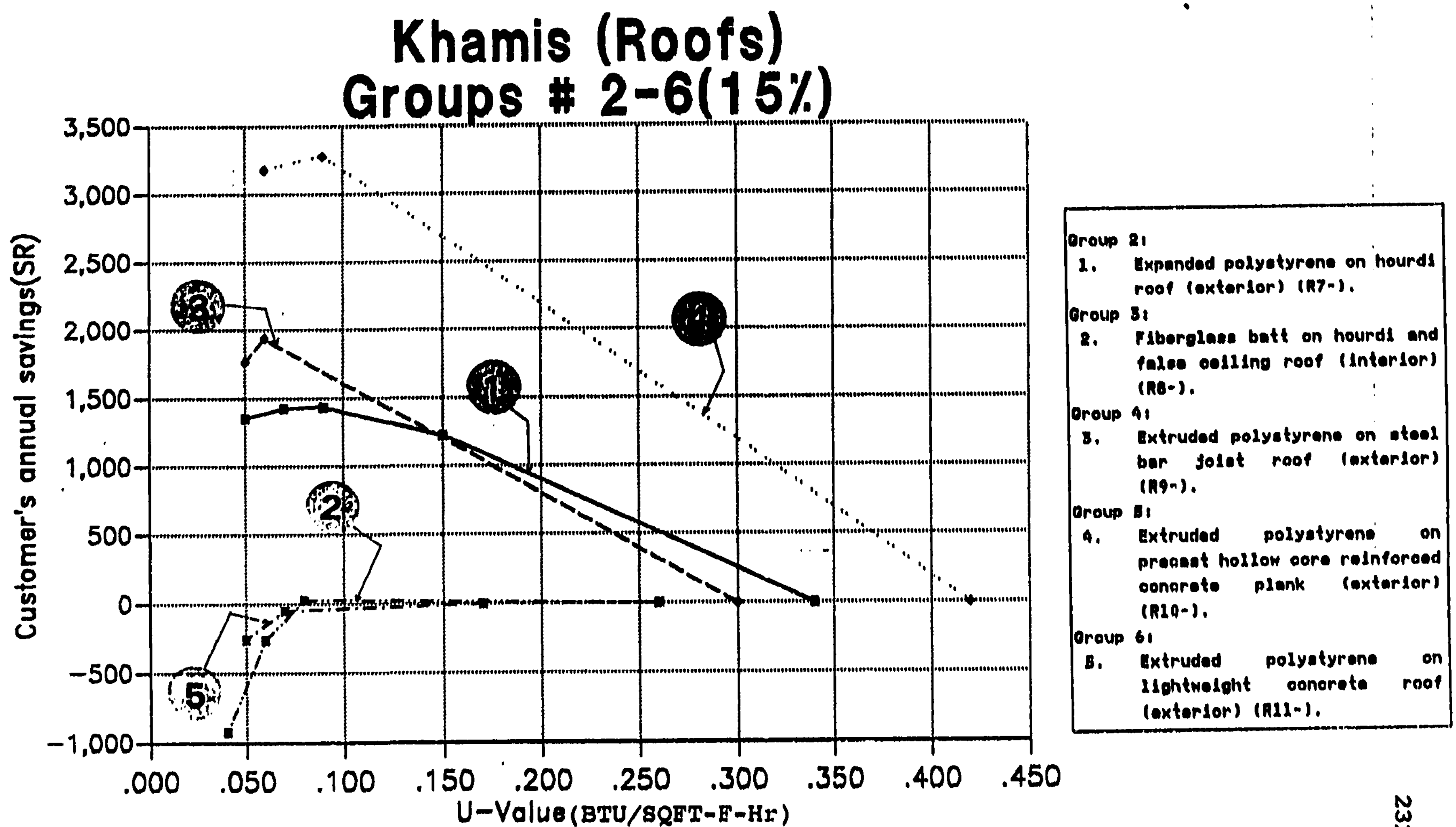


__Figure 7.32__: Khamis - Roofs # 2-6 (Thermal performance at 15%)

7.4 Results of the sensitivity analysis

In order to see the differences between the three discount rates, the thermal performance figures of the 10% discount rate for each city (Chapter 6) should be compared with Figures 7.1 through 7.32. For comparison, Figure 6.16 shows that the exterior polyurethane board on a CMU wall (W6-1-3) will give the best customer's annual savings of about SR 6100 with a U-value of 0.050 BTU/SQFT-F-Hr when a 10% discount rate is used. Figure 7.1 shows that the same material at a discount rate of 5% will give a lower customer's annual savings of about SR 5600 at the same U-value. Figure 7.17 shows that with a discount rate of 15%, the same material will also give the best customer's annual savings of about SR 6700 at the same U-value.

By comparing the rest of the figures, it could be seen that the discount rate will affect the amount of annual savings only and not the relative performance of the thermal insulation materials. It is clear that the discount rate is directly proportional to the amount of savings.

Chapter 8
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

8.1 Summary

In this study, a typical Saudi villa with different wall and roof configurations was utilized. The data for the villa was entered into the DOE-2.1C computer program for the sake of simulating the thermal performance of the typical villa in four different Saudi cities (Dhahran, Riyadh, Jeddah and Khamis Mushait). The results obtained from the simulation outputs were then analysed economically by the use of a selected economic model. The results of the economic analysis helped in the process of evaluating the performance of the villa in each city, for both government and customers, and thus a comparison study could be achieved. A sensitivity analysis was also performed to validate the selection of a discount rate. The final results led to the definition of the required U-values in the Saudi Arabian environment and also led to the magnification of the role of thermal insulation in Saudi Arabian buildings.

8.2 Conclusions

The general conclusions of this study are:

1. In Saudi Arabia, walls require either the same thickness or thicker insulation than roofs.
2. Riyadh city has the most economic benefits from using insulation materials. Jeddah comes in the second place, then Dhahran and lastly comes Khamis Mushait.
3. For walls, locating the insulation material on the interior has no economical or thermal difference from locating it on the exterior.
4. For roofs, putting the insulation material on the exterior is better from the economic point of view than putting it on the interior.
5. The change of discount rate has no effect on the relative performance of the insulation materials. The only effect it has is on the amount of annual savings.
6. There is a significant annual savings for the customers ranging from SR 1000 to SR 11000 when using insulations in buildings.
7. The government makes more significant annual savings ranging from SR 2500 to SR 17000 when using insulations in buildings.

Some other specific conclusions which deserve mentioning are:

1. Extruded polystyrene has a better thermal performance than expanded polystyrene. But economically, they are almost the same.
2. Expanded polystyrene has the same thermal performance whether used on a reinforced concrete or a hourdi roof. But economically, on a reinforced concrete roof it becomes more economical.
3. A 50mm polyurethane board has almost the same economic performance of a 75mm expanded polystyrene board.
4. Clay tiles will give savings even with no insulation used.

Table 7.1 shows the average U-values for the four major cities in the Kingdom of Saudi Arabia for the customers. Table 7.2 shows the average U-values for the four major cities in the Kingdom of Saudi Arabia for the government. For each city, a single U-value, which is relevant to the maximum savings, is given. In addition to this, a range, within which good economic performance is achieved, is given.

Table 8.1: Average U-values for Saudi Arabia (Customers).

	Walls (BTU/SQFT-F-Hr)			Roofs (BTU/SQFT-F-Hr)		
	Max. saving	Lower 10%	Higher 10%	Max. saving	Lower 10%	Higher 10%
Dhahran	0.072	0.072	0.114	0.067	0.055	0.083
Riyadh	0.076	0.070	0.114	0.062	0.053	0.107
Jeddah	0.076	0.070	0.112	0.073	0.053	0.112
Khamis	0.082	0.070	0.118	0.078	0.052	0.108

Table 8.2: Average U-values for Saudi Arabia (Government).

	Walls (BTU/SQFT-F-Hr)			Roofs (BTU/SQFT-F-Hr)		
	Max. saving	Lower 10%	Higher 10%	Max. saving	Lower 10%	Higher 10%
Dhahran	0.072	0.072	0.102	0.060	0.053	0.083
Riyadh	0.070	0.070	0.106	0.050	0.050	0.082
Jeddah	0.070	0.070	0.104	0.050	0.050	0.082
Khamis	0.070	0.070	0.108	0.050	0.050	0.087

8.3 Recommendations

8.3.1 General recommendations

In this study, it is not intended to recommend a specific construction configuration which could give the maximum savings to be used for the Kingdom. Such recommendations will restrict implementation of different construction configuration approaches and would prevent the development of new construction materials in Saudi Arabia.

As a result of this study, it is highly recommended to use thermal insulation materials in Saudi Arabian residential buildings. This study showed how important and economical the use of thermal insulation materials is in the Kingdom. The government should encourage the consumer's energy savings by the institution of laws that reward these savings.

8.3.2 Recommendations for further research

For further research, the following is recommended:

1. It is recommended to study the economic performance of Saudi Arabian commercial buildings.
2. It is recommended to study the multistorey residential buildings.
3. It is recommended to establish a data base for a cost index of insulation materials.
4. An expert system could be used to present the results of this study easily, so that a handy program could be used by the constructors to find out the best insulation material to be used.

Appendix A
Insulation Materials Prices [15]

TYPE : FIBERGLASS (15)

DATE : MARCH 3, 1990

MANUFACTURER : ARABIAN FIBERGLASS INSULATION COMPANY

1- BOARD-UNFACED

FORM \ DATA	LOCATION OF USE	TYPE OF USE	THICKNESS (mm)	DENSITY (kg/m^3)	MATERIAL COST (SR/m^2)
BOARD-UNFACED 480 (1.2m x 1m)	WALL	EXTER. SANDW.	25	48	9.97
" " " " " " " " " "	" " "	" " "	38	48	15.05
" " " " " " " " " "	" " "	" " "	50	48	19.95
BOARD-UNFACED 640 (1.2m x 1m)	" " "	" " "	25	64	12.95
" " " " " " " " " "	" " "	" " "	38	64	19.60
" " " " " " " " " "	" " "	" " "	50	64	25.90
BOARD-UNFACED 960 (1.2m x 1m)	" " "	" " "	25	96	18.37
" " " " " " " " " "	" " "	" " "	38	96	27.83
" " " " " " " " " "	" " "	" " "	50	96	36.75

TYPE : FIBERGLASS (15)

DATE : MARCH 3, 1990

MANUFACTURER : ARABIAN FIBERGLASS INSULATION COMPANY

2- BLANKET

DATA / FORM	LOCATION OF USE	TYPE OF USE	THICKNESS (mm)	DENSITY (kg/m^3)	MATERIAL COST (SR/m^2)
BLANKET-UNFACED	WALL	EX, IN, SANDW.	64	10	6.68
" " " " " " " "	" " "	" " "	75	10	7.63
" " " " " " " "	" " "	" " "	89	10	8.89
" " " " " " " "	" " "	" " "	100	10	9.91
" " " " " " " "	" " "	" " "	150	10	15.09
BLANKET-KRAFT	" " "	" " "	64	10	7.70
" " " " " " "	" " "	" " "	75	10	8.82
" " " " " " "	" " "	" " "	89	10	10.05
" " " " " " "	" " "	" " "	100	10	11.02
" " " " " " "	" " "	" " "	150	10	16.31

TYPE : FIBERGLASS (CONTINUE)(15)

DATE : MARCH 3, 1990

MANUFACTURER : ARABIAN FIBERGLASS INSULATION COMPANY

2- BLANKET

FORM \ DATA	LOCATION OF USE	TYPE OF USE	THICKNESS (mm)	DENSITY (kg/m^3)	MATERIAL COST (SR/m^2)
BLANKET-FOIL	WALL	EX, IN, SANDW.	64	10	8.47
" " " " " "	" " "	" " "	75	10	9.07
" " " " " "	" " "	" " "	89	10	10.43
" " " " " "	" " "	" " "	100	10	11.34
" " " " " "	" " "	" " "	150	10	16.52
BLANKET-F.R.K.	" " "	" " "	64	10	9.48
" " " " " " "	" " "	" " "	75	10	9.91
" " " " " " "	" " "	" " "	89	10	11.2
" " " " " " "	" " "	" " "	100	10	11.76
" " " " " " "	" " "	" " "	150	10	17.71

TYPE : FIBERGLASS (CONTINUE)(15)

DATE : MARCH 3, 1990

MANUFACTURER : ARABIAN FIBERGLASS INSULATION COMPANY

3- BLANKET TYPE HD (UNFACED)

FORM \ DATA	LOCATION OF USE	TYPE OF USE	THICKNESS (mm)	DENSITY (kg/m^3)	MATERIAL COST (SR/m^2)
HD-16 (UNFACED)	WALL	EX. IN, SANDW.	25	16	4.27
" " " " " " " "	" " "	" " "	38	16	5.37
" " " " " " " "	" " "	" " "	50	16	7.10
" " " " " " " "	" " "	" " "	64	16	9.30
" " " " " " " "	" " "	" " "	75	16	10.82
HD-24 (UNFACED)	" " "	" " "	25	24	5.27
" " " " " " " "	" " "	" " "	38	24	7.7
" " " " " " " "	" " "	" " "	50	24	10.12
" " " " " " " "	" " "	" " "	64	24	13.16

TYPE : FIBERGLASS (CONTINUE)(15)

DATE : MARCH 3, 1990

MANUFACTURER : ARABIAN FIBERGLASS INSULATION COMPANY

3- BLANKET TYPE HD (KRAFT)

FORM \ DATA	LOCATION OF USE	TYPE OF USE	THICKNESS (mm)	DENSITY (kg/m³)	MATERIAL COST (SR/m²)
HD-16 (KRAFT)	WALL	EX, IN, SANDW.	25	16	5.37
" " " " " " " "	" " "	" " "	38	16	6.52
" " " " " " " "	" " "	" " "	50	16	8.20
" " " " " " " "	" " "	" " "	64	16	10.39
" " " " " " " "	" " "	" " "	75	16	11.87
HD-24 (KRAFT)	" " "	" " "	25	24	6.22
" " " " " " " "	" " "	" " "	38	24	8.85
" " " " " " " "	" " "	" " "	50	24	11.22
" " " " " " " "	" " "	" " "	64	24	14.26

TYPE : FIBERGLASS (CONTINUE)(15)

DATE : MARCH 3, 1990

MANUFACTURER : ARABIAN FIBERGLASS INSULATION COMPANY

3- BLANKET TYPE HD (FOIL REINFORCED KRAFT)

FORM \ DATA	LOCATION OF USE	TYPE OF USE	THICKNESS (mm)	DENSITY (kg/m³)	MATERIAL COST (SR/m²)
HD-16 (FRK)	WALL	EX, IN, SANDW.	25	16	6.1
" " " " " "	" " "	" " "	38	16	7.68
" " " " " "	" " "	" "	50	16	8.92
" " " " " "	" " "	" "	64	16	11.96
" " " " " "	" " "	" "	75	16	13.21
HD-24 (FRK)	" " "	" " "	25	24	7.38
" " " " " "	" " "	" " "	38	24	10.60
" " " " " "	" " "	" " "	50	24	12.67
" " " " " "	" " "	" " "	64	24	17.53

TYPE : FIBERGLASS (CONTINUE)(15)

DATE : MARCH 3, 1990

MANUFACTURER : ARABIAN FIBERGLASS INSULATION COMPANY

4- ROOF INSULATION

FORM \ DATA	LOCATION OF USE	TYPE OF USE	THICKNESS (mm)	DENSITY (kg/m^3)	MATERIAL COST (SR/m^2)
INSULATION BOARD	ROOF	REGUL.	25	122	17.36
" " " " "" " " "	" " "	" " "	33	122	23.1
" " " " " " " "	" " "	" " "	38	122	25.45
" " " " " " " "	" " "	" " "	44	122	29.1
" " " "" " " "	" " "	" " "	50	122	32.73

TYPE : FIBERGLASS (CONTINUE)(15)

DATE : MARCH 3, 1990

MANUFACTURER : ARABIAN FIBERGLASS INSULATION COMPANY

5- ROOF DECK BOARD

FORM \ DATA	LOCATION OF USE	TYPE OF USE	THICKNESS (mm)	DENSITY (kg/m^3)	MATERIAL COST (SR/m^2)
INSULATION BOARD	ROOF	REGUL.	25	122	14.00
" " " " " " " "	" " "	" " "	38	122	21.42
" " " " " " " "	" " "	" " "	50	122	28.00
" " " " " " " "	" " "	" " "	57	122	31.85
" " " " " " " "	" " "	" " "	64	122	35.84

TYPE : VERMICULITE ZONOLITE (15)
DATE : MARCH 6,1990
MANUFACTURER : ARABIAN VERMICULITE INDUSTRIES

DATA / FORM	LOCATION OF USE	TYPE OF USE	THICKNESS (mm)	DENSITY (kg/m³)	MATERIAL COST (SR/m²)
LOOS FILL	ROOF	LIGH.W CONCR.	50	40	18.5
" " " " "	" " "	" " "	65	40	23.0
" " " " "	WALL	SANDW.	40	25	13.5
" " " " "	" " "	" " "	40	30	15.5
" " " " "	" " "	" " "	30	25	11.0

TYPE : EXTRUDED POLYSTYRENE (15)

DATE : MARCH 11, 1990

MANUFACTURER : THE ARABIAN CHEMICAL COMPANY

DATA / FORM	LOCATION OF USE	TYPE OF USE	THICKNESS (mm)	DENSITY (kg/m^3)	MATERIAL COST (SR/m^2)
ROOFMATE	ROOF	INVER.	50	32-35	22.5
WALLMATE	WALL	SANDW.	40	26	17.2
WALLMATE	WALL	SANDW.	50	24	21.5
WALLMATE WITH 9.5mm GYPSUM BOARD	WALL	INTER.	50	26	40
WALLMATE WITH 9.5mm GYPSUM BOARD	WALL	INTER.	40	26	35
ROOFMATE WITH CONCRETE TILE	ROOF	INVER.	50	32-35	55

TYPE : GLASS WOOL (15)

DATE : MARCH 13, 1990

MANUFACTURER : KUWAIT INSULATING MATERIAL MANUFACTURING COMPANY (KIMMCO)

1- DUCTWRAP KDW

FORM \ DATA	LOCATION OF USE	TYPE OF USE	THICKNESS (mm)	DENSITY (kg/m³)	MATERIAL COST (SR/m²)
DUCTWRAP (KDW) WITH FSK FACING 20mx1.2m	AIR DUCTS	EXTER.	25	10	5.48
" " " " " " " " "	" " "	" " "	40	10	7.75
" " " " " " " " "	" " "	" " "	50	10	8.20
" " " " " " " " "	" " "	" " "	25	12	5.90
" " " " " " " " "	" " "	" " "	40	12	7.25
" " " " " " " " "	" " "	" " "	50	12	9.0
" " " " " " " " "	" " "	" " "	25	16	6.8
" " " " " " " " "	" " "	" " "	40	16	8.60
" " " " " " " " "	" " "	" " "	50	16	10.25
" " " " " " " " "	" " "	" " "	25	24	8.00
" " " " " " " " "	" " "	" " "	40	24	11.50
" " " " " " " " "	" " "	" " "	50	24	13.90

TYPE : GLASS WOOL (CONTINUE) (15)

DATE : MARCH 13, 1990

MANUFACTURER : KUWAIT INSULATING MATERIAL MANUFACTURING COMPANY (KIMMCO)

2- DUCTBOARD KDB

FORM \ DATA	LOCATION OF USE	TYPE OF USE	THICKNESS (mm)	DENSITY (kg/m^3)	MATERIAL COST (SR/m^2)
DUCTBOARD (KDB) WITH FSK FACING 1.2mx1m	WALL, ROOF	INTER, REGUL.	25	24	8.0
" " " " " " " " " "	" " "	" " "	40	24	11.5
" " " " " " " " " "	" " "	" " "	50	24	13.90
" " " " " " " " " "	" " "	" " "	25	32	10.50
" " " " " " " " " "	" " "	" " "	40	32	15.80
" " " " " " " " " "	" " "	" " "	50	32	19.30
" " " " " " " " " "	" " "	" " "	25	48	16.25
" " " " " " " " " "	" " "	" " "	40	48	22.30
" " " " " " " " " "	" " "	" " "	50	48	28.25

TYPE : GLASS WOOL (CONTINUE) (15)

DATE : MARCH 13, 1990

MANUFACTURER : KUWAIT INSULATING MATERIAL MANUFACTURING COMPANY (KIMMCO)

3- DUCTLINER KDL

FORM \ DATA	LOCATION OF USE	TYPE OF USE	THICKNESS (mm)	DENSITY (kg/m^3)	MATERIAL COST (SR/m^2)
DUCTLINER (KDL) WITH BGT FACING 20mx1.2m	DUCTS	INTER.	25	16	9.35
" " " " " " " " " "	" " "	" " "	40	16	11.1
" " " " " " " " " "	" " "	" " "	50	16	12.85
" " " " " " " " " "	" " "	" " "	25	24	11.65
" " " " " " " " " "	" " "	" " "	40	24	15.5
" " " " " " " " " "	" " "	" " "	50	24	18.0
DUCTLINER (KDL) WITH BGT FACING 1.2mx1m	" " "	" " "	25	48	19.5
" " " " " " " " " "	" " "	" " "	40	48	27.5
" " " " " " " " " "	" " "	" " "	50	48	33.50

TYPE : EXPANDED POLYSTYRENE (15)

DATE : APRIL 1, 1990

MANUFACTURER : AL-HAJRY INSULATION INDUSTRIES

DATA / FORM	LOCATION OF USE	TYPE OF USE	DENSITY (kg/m^3)	MATERIAL COST (SR/m^3)	MATERIAL COST (SR/m^2)
EXP. POLYSTY. BOARD (Thickness= 50mm)	WALL, ROOF	SANDW. REGUL.	16	190	9.5
" " " " " " " " " "	" " "	" " "	20	220	11
" " " " " " " " " "	" " "	" " "	24	240	12
" " " " " " " " " "	" " "	" " "	30	290	14.5
" " " " " " " " " "	" " "	" " "	35	360	18

TYPE : POLYURETHANE (15)

DATE : MARCH 25, 1990

MANUFACTURER : AL-BABTAIN URETHANE COMPANY

FORM \ DATA	LOCATION OF USE	TYPE OF USE	THICKNESS (mm)	DENSITY (kg/m^3)	MATERIAL COST (SR/m^2)
SPRAY SYSTEM	ROOF, WALL	REGUL. SANDW.	25	40	28
" " " " " "	" " "	" " "	50	55	40
" " " " " "	" " "	" " "	60	48	54
SPRAY WITH 0.5mm DIATHON LAYER	WALL	SANDW.	25	40	48
" " " " " " " " "	ROOF	REGUL.	25	40	47.5

DATE : APRIL 8, 1990

TYPE : EXPANDED POLYSTYRENE BOARD ,
POLYURETHANE BOARD. (15)

MANUFACTURER : SAPPCO-TEXACO INSULATION PRODUCTS COMPANY

FORM \ DATA	LOCATION OF USE	TYPE OF USE	THICKNESS (mm)	DENSITY (kg/m^3)	MATERIAL COST (SR/m^2)
EXPANDED POLYSTYRENE BOARD	WALL	SANDW.	25	20	5.0
" " " " " " " " " "	WALL	" " "	50	20	10.0
" " " " " " " " " "	WALL	" " "	75	20	15.0
" " " " " " " " " "	ROOF	REGUL.	25	30	7.5
" " " " " " " " " "	ROOF	" " "	50	30	15.0
" " " " " " " " " "	ROOF	" " "	75	30	22.5
POLYURETHANE BOARD (KRAFT FACINGS)	WALL	" " "	25	30-35	13.7
" " " " " " " " " "	WALL	" " "	50	30-35	21.8
" " " " " " " " " "	WALL	" " "	75	30-35	31.4

TYPE : EXTRUDED POLYSTYRENE (15)

DATE : APRIL 15, 1990

MANUFACTURER : AL-ZAMIL FOR INSULATION (ESSCO)

FORM \ DATA	LOCATION OF USE	TYPE OF USE	THICKNESS (mm)	DENSITY (kg/m^3)	MATERIAL COST (SR/m^2)
ROOFMATE	ROOF	INVER.	50	35	19
ROOFMATE	ROOF	INVER.	50	26	18
WALLMATE	WALL	SANDW.	50	21	17
WALLMATE WITH 9.5mm GYPSUM BOARD	WALL	INTER.	50	21	46
ROOFMATE WITH 20mm CONCRETE TILE	ROOF	INVER.	50	35	55

TYPE : FOAMGLAS (15)
DATE : MARCH 18, 1990
MANUFACTURER : BINZAGR FACTORY FOR INSULATION MATERIALS

DATA / FORM	LOCATION OF USE	TYPE OF USE	THICKNESS (mm)	DENSITY (kg/m³)	MATERIAL COST (SR/m²)
CELLULAR GLASS FOR BUILDING	WALL, ROOF	SANDW., INVER.,	40	136	69
" " " " " " " " "	" " "	" " " "	50	136	92
" " " " " " " " "	" " "	" " " "	65	136	115
" " " " " " " " "	" " "	" " " "	75	136	138
" " " " " " " " "	" " "	" " " "	100	136	184

TYPE : POLYISOCYANURATE (15)

DATE : MARCH 20, 1990

MANUFACTURER : AL-HOWISH ELWIN G.SMITH COMPANY (HESCO)

DATA / FORM	LOCATION OF USE	TYPE OF USE	THICKNESS (mm)	DENSITY (kg/m³)	MATERIAL COST (SR/m²)
VARIFOAM	ROOF, WALL	SANDW. PANEL	55	35-45	125
" " " "	" " "	" " "	57	" " "	140
" " " "	" " "	" " "	58	" " "	155
" " " "	" " "	" " "	100	" " "	170
" " " "	" " "	" " "	125	" " "	185
" " " "	" " "	" " "	150	" " "	200
" " " "	" " "	" " "	175	" " "	215
" " " "	" " "	" " "	205	" " "	230
DRYVIT OUTSULATION	WALL	EXTER.	50	20	75

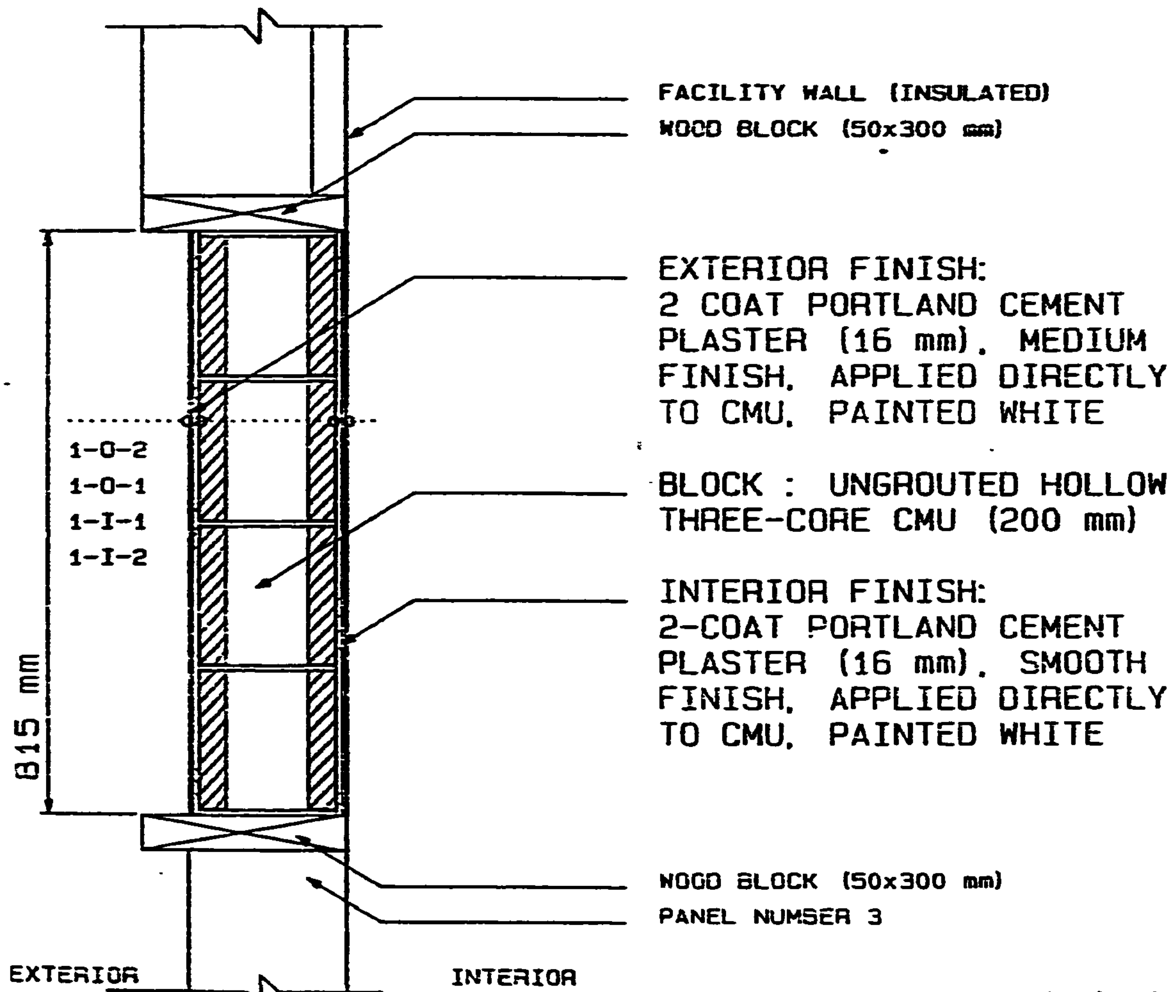
TYPE : PERLITE (15)
DATE : APRIL 19, 1990
MANUFACTURER : SAUDI PERLITE INDUSTRIES

DATA / FORM	LOCATION OF USE	TYPE OF USE	THICKNESS (mm)	DENSITY (kg/m^3)	MATERIAL COST (SR/m^2)
LOOSE FILL	WALL	SANDW.	50	/	8.5
" " " " " "	ROOF	LIGH.W CONCR.	80	/	16.0

Appendix B
Insulation Materials Installation Costs [15]

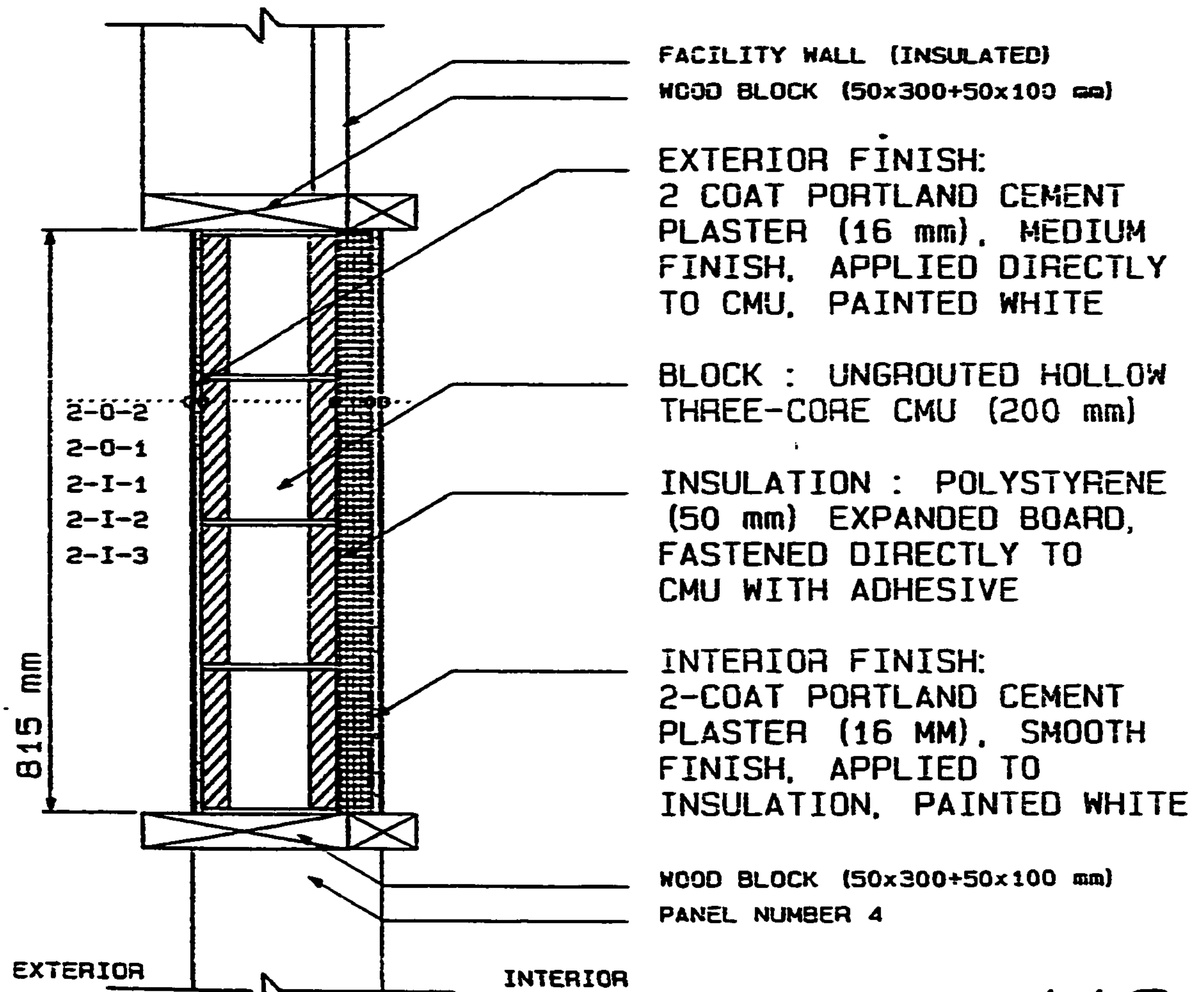
costs / Form	installation costs SR/sq M					Comments
	sandwich Wall	interior Wall	exterior Wall	inverted Roof	regular Roof	
BOARD	1-5	2.5-10	20-30	15-20	7-12	
FOAM	3-5	3-5	3-5	3-5	3-5	
FIBER	2-7	5-10	-	5-9	5-9	
GRANULAR	1	-	-	Foam Concrete 6-9	Foam Concrete 6-9	

Appendix C
Wall and Roof Configurations [17]



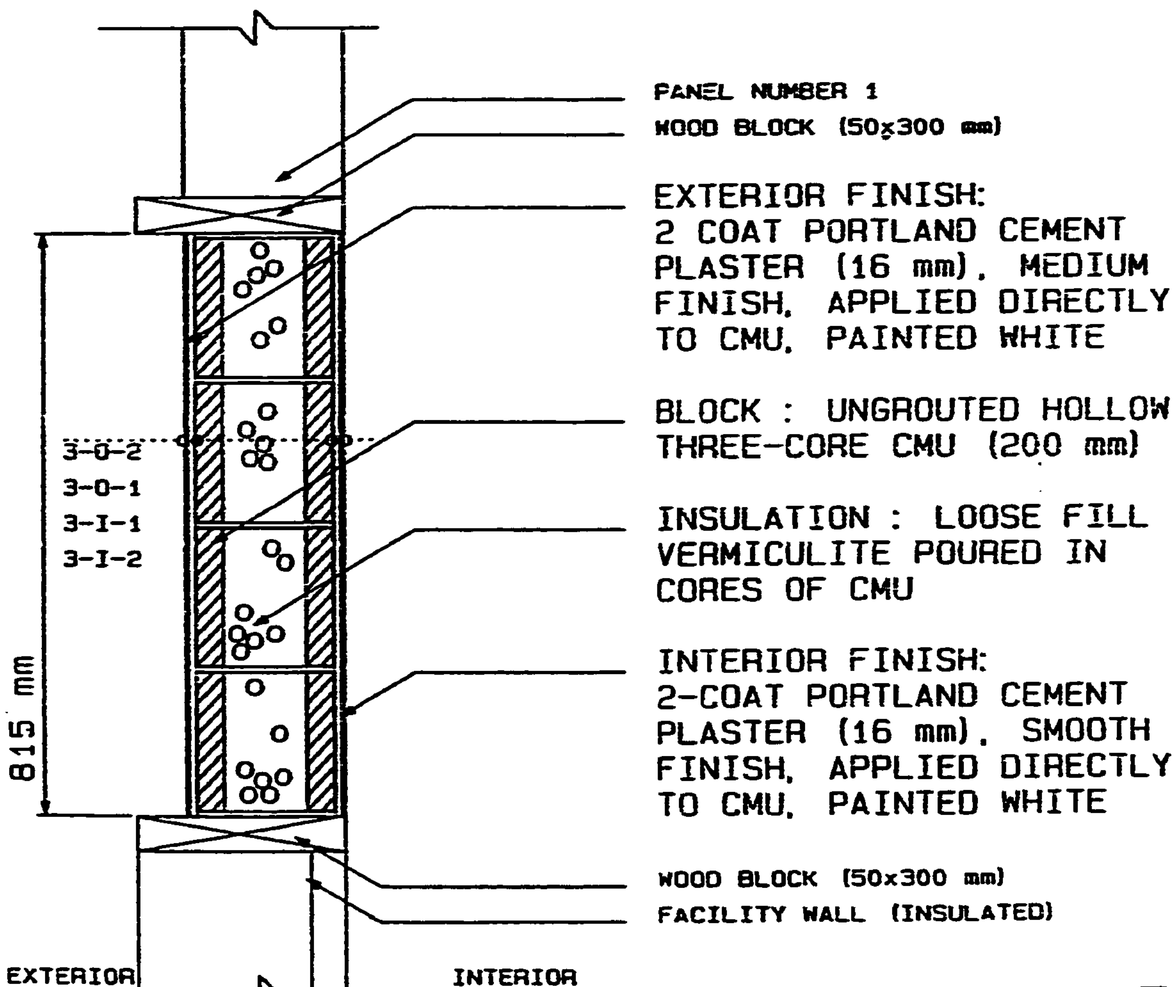
WALL PANEL SECTION 1: 10

W 1



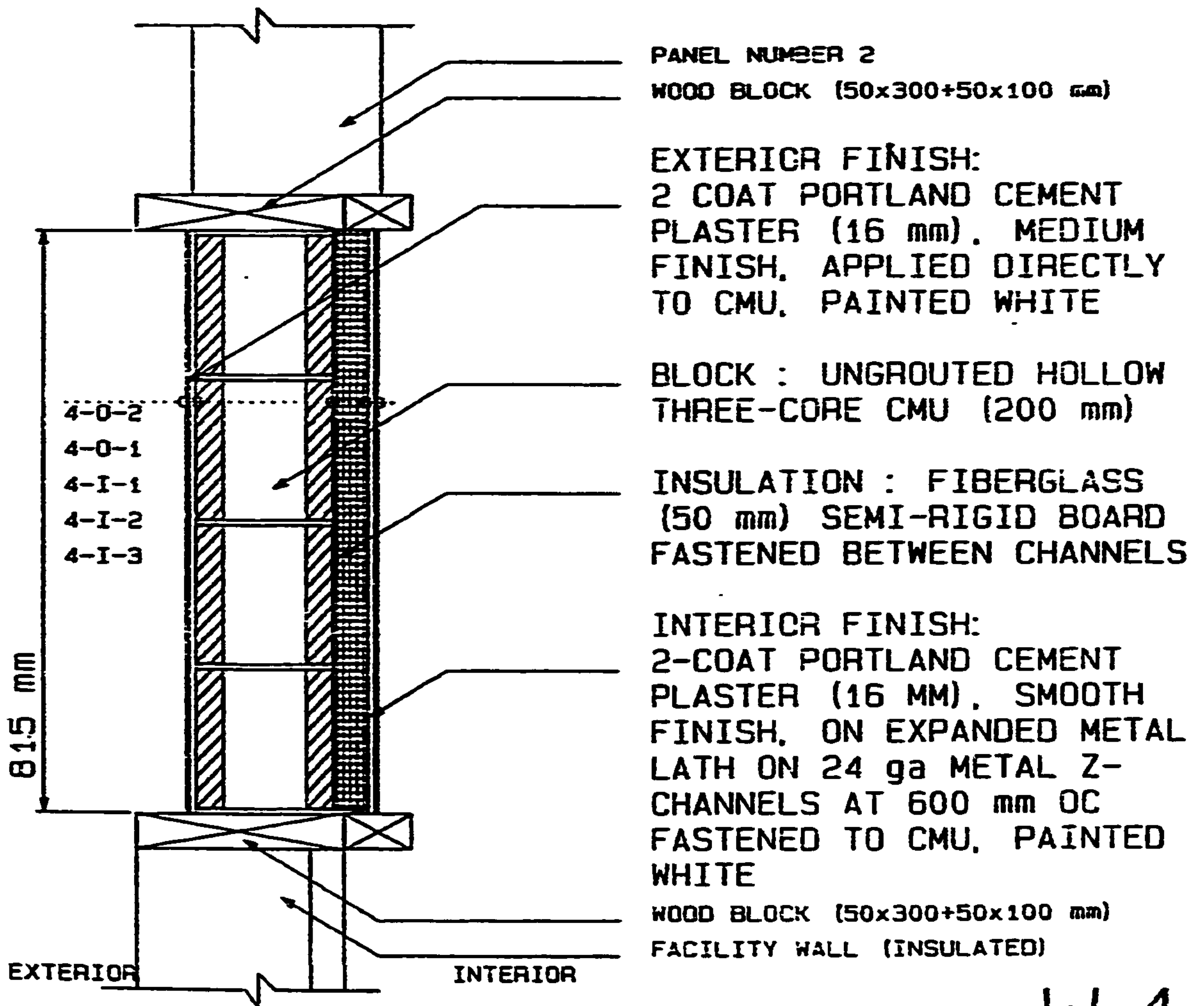
WALL PANEL SECTION 1: 10

W2



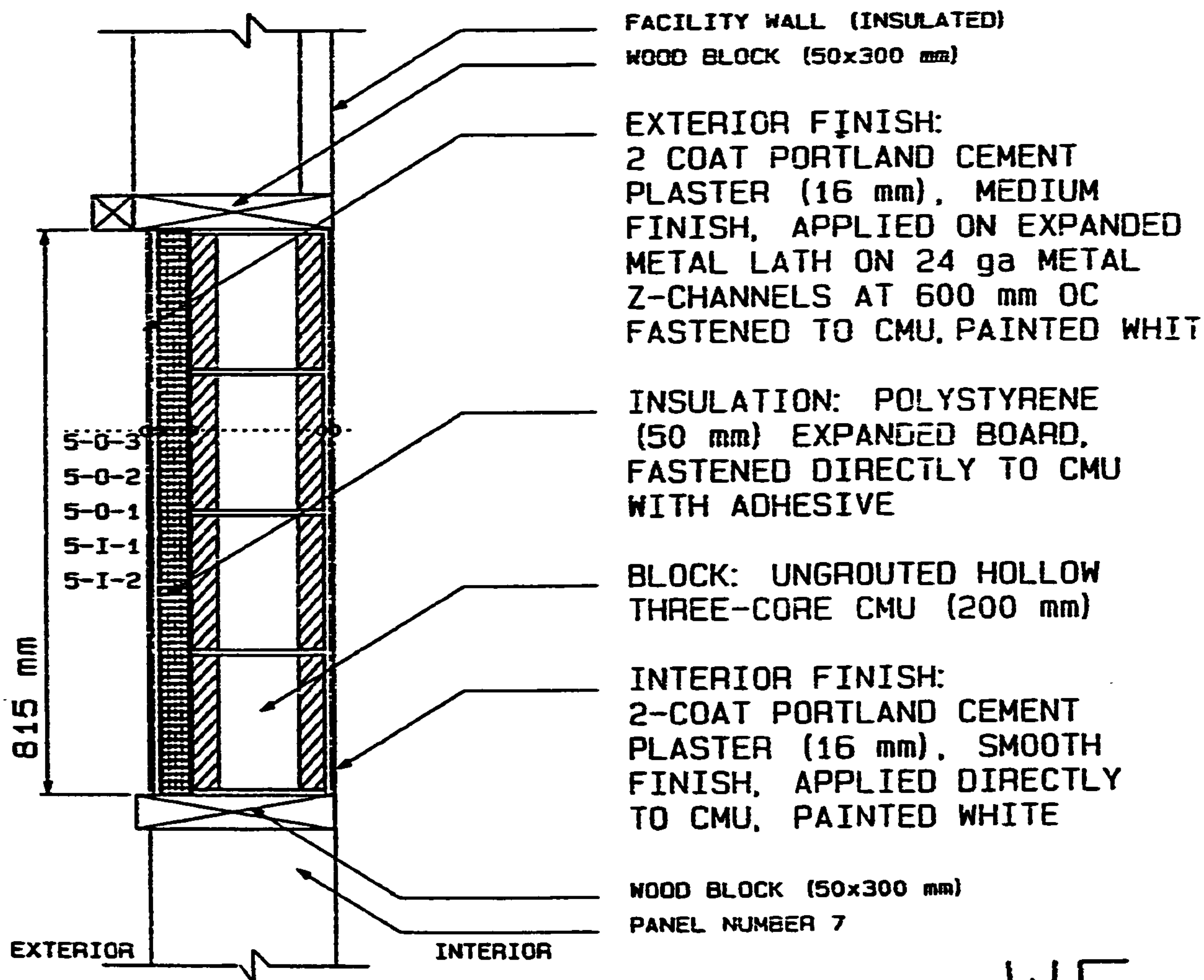
WALL PANEL SECTION 1: 10

W3



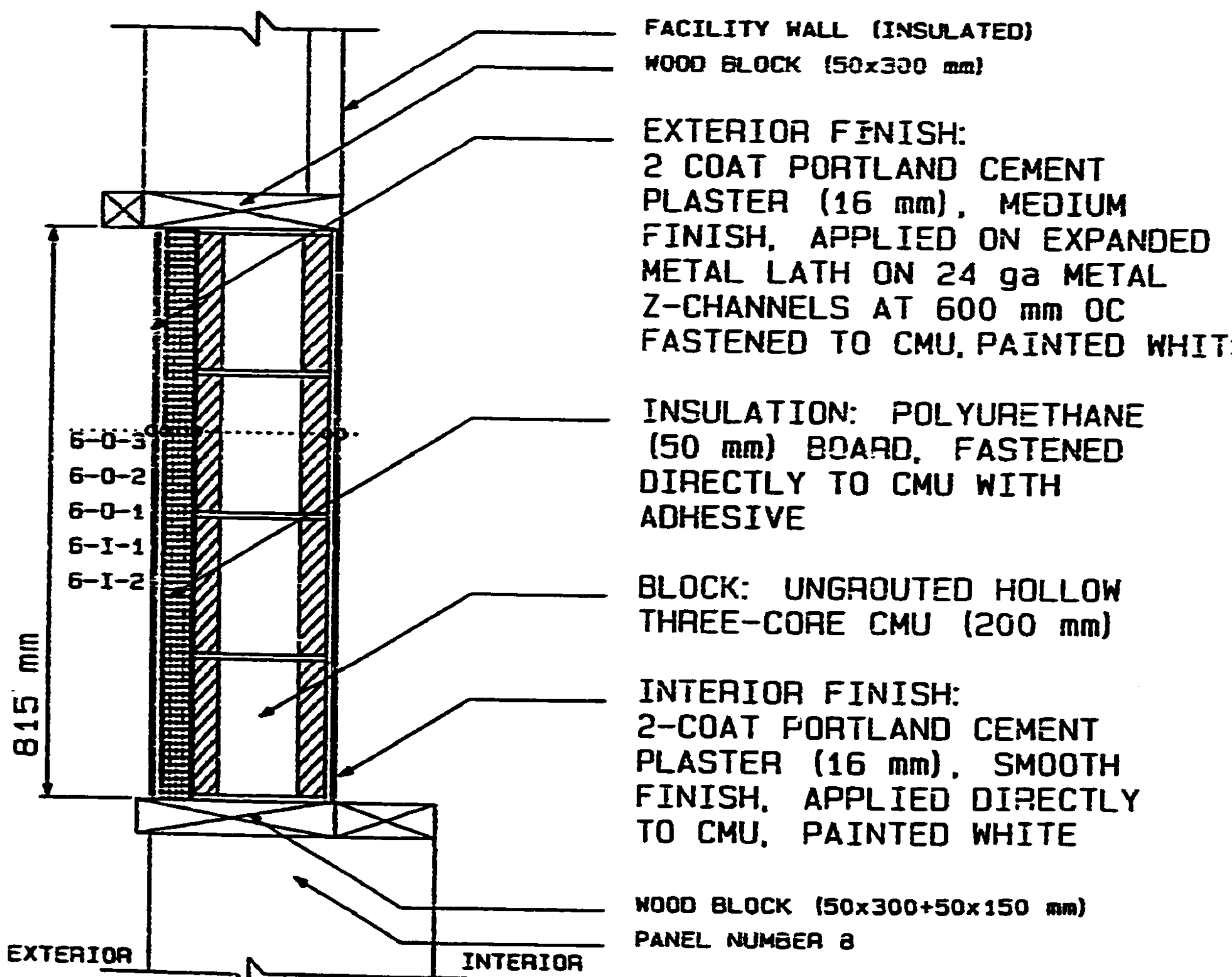
WALL PANEL SECTION 1: 10

W4



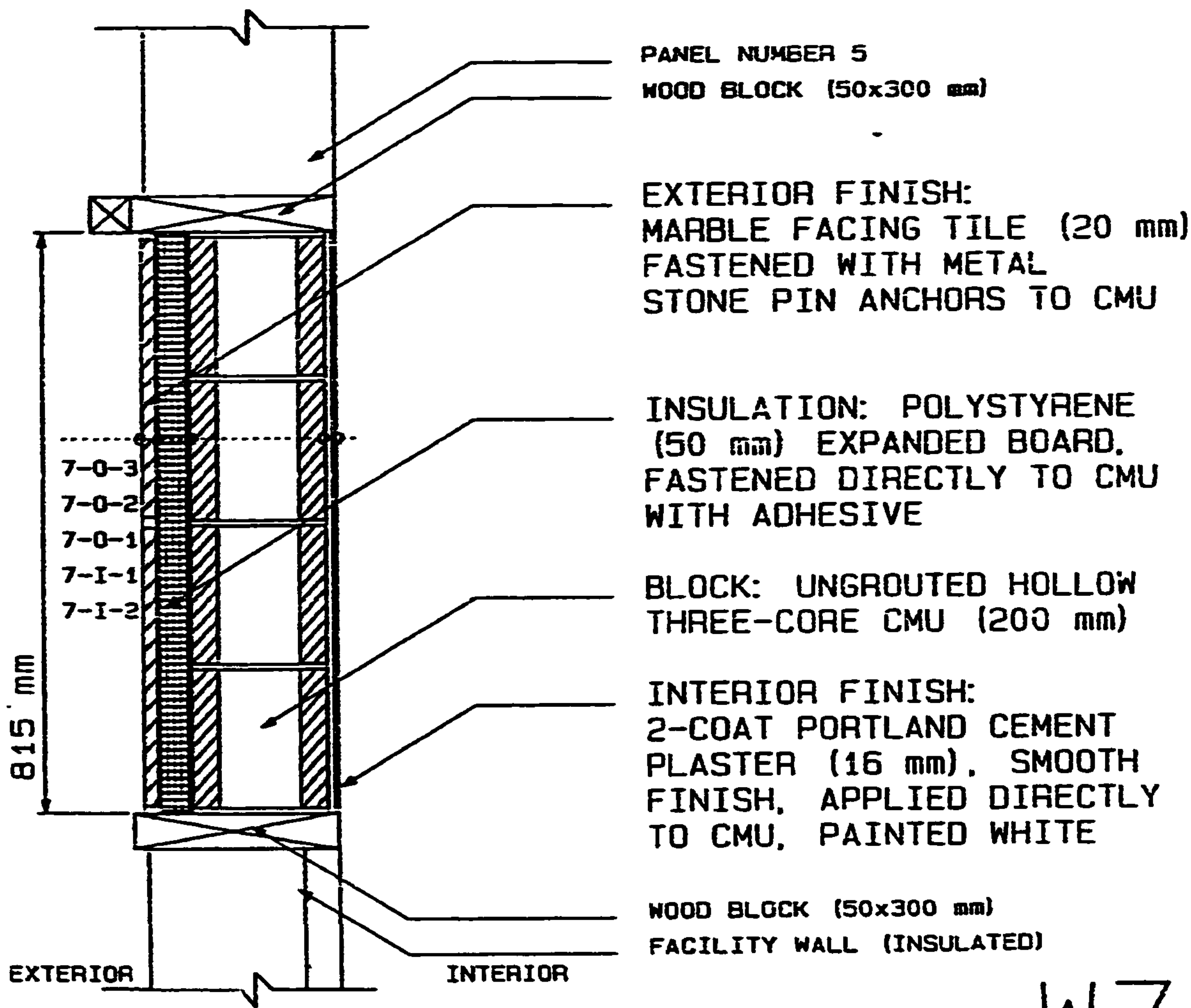
WALL PANEL SECTION 1: 10

W5



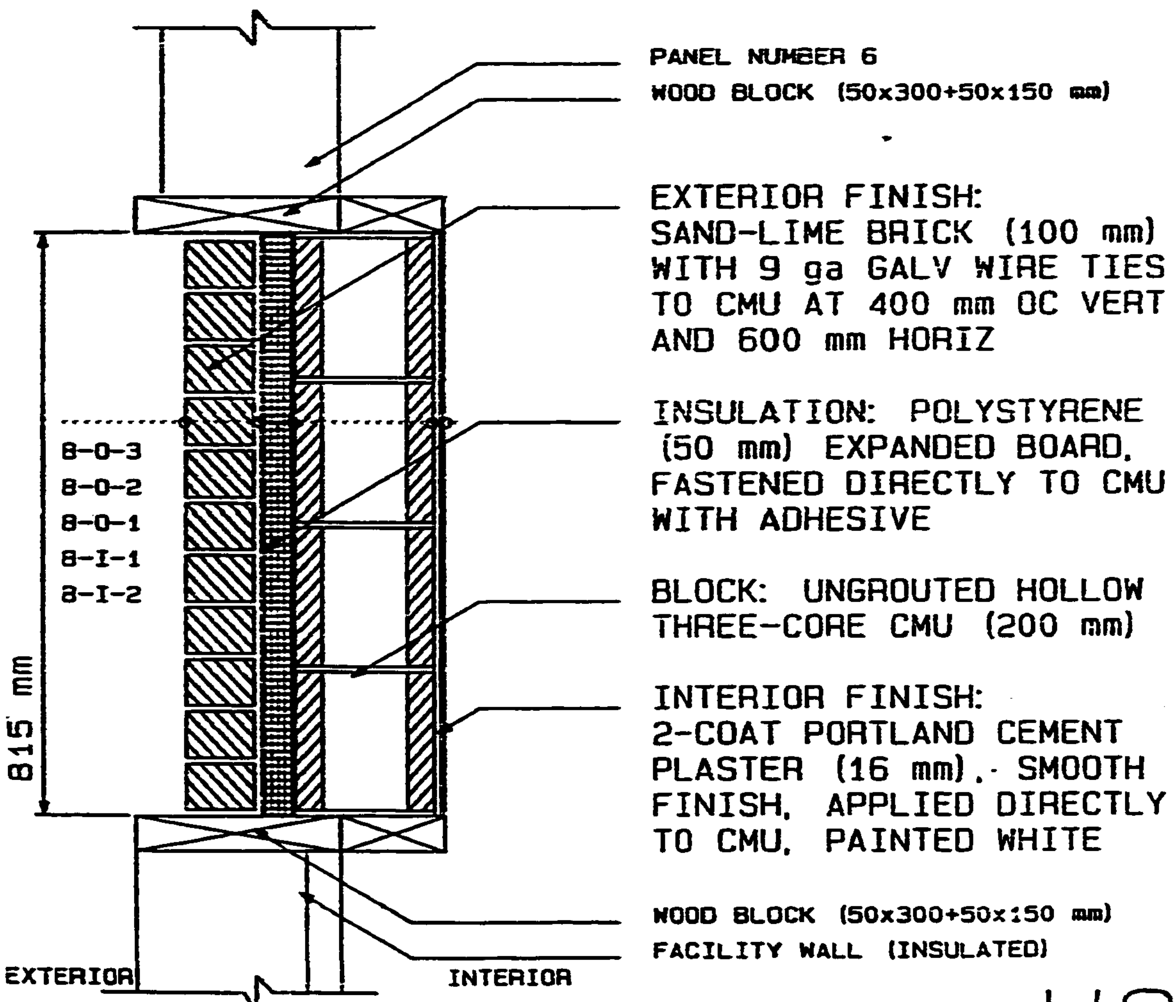
WALL PANEL SECTION 1: 10

W6



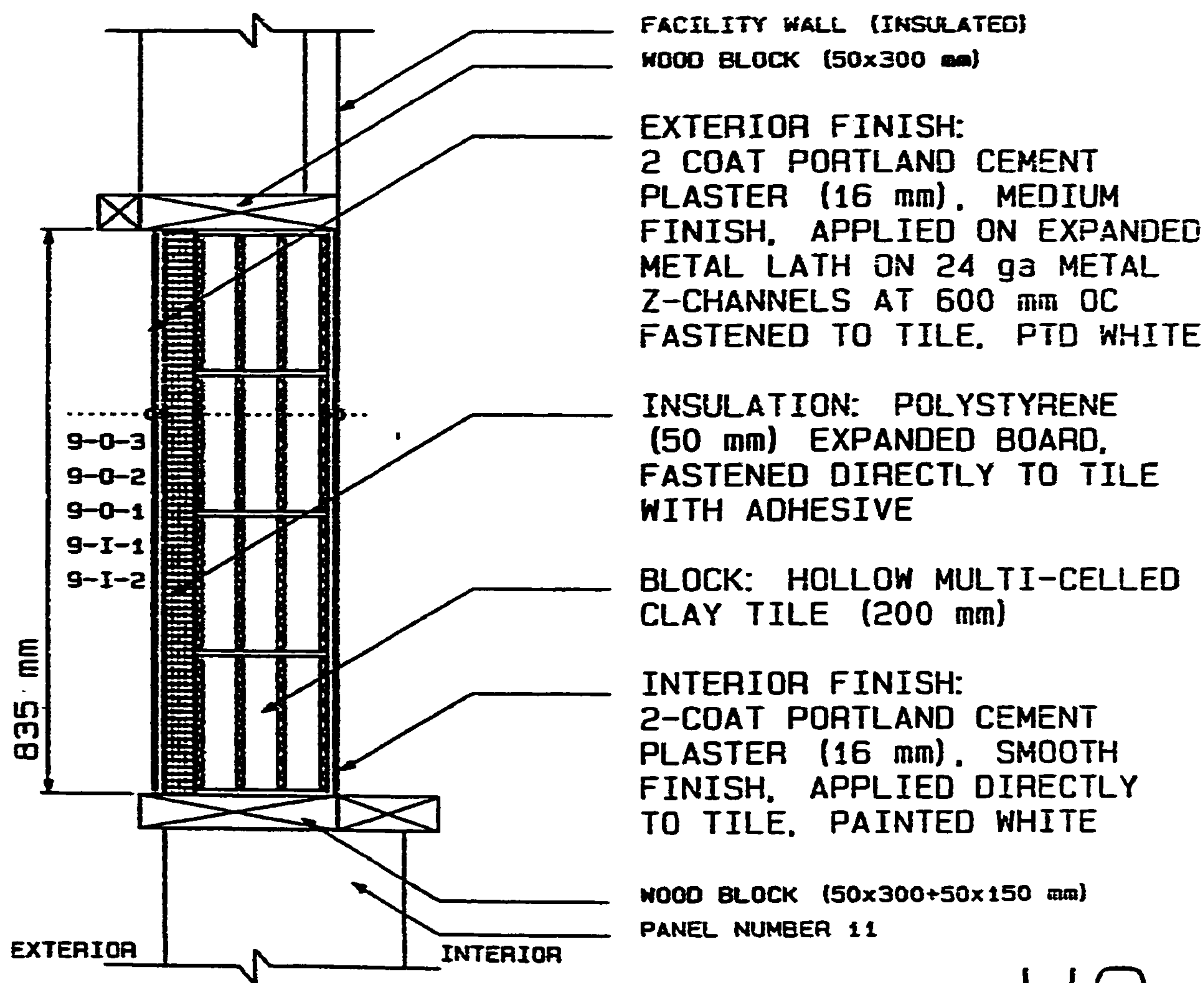
WALL PANEL SECTION 1: 10

W7



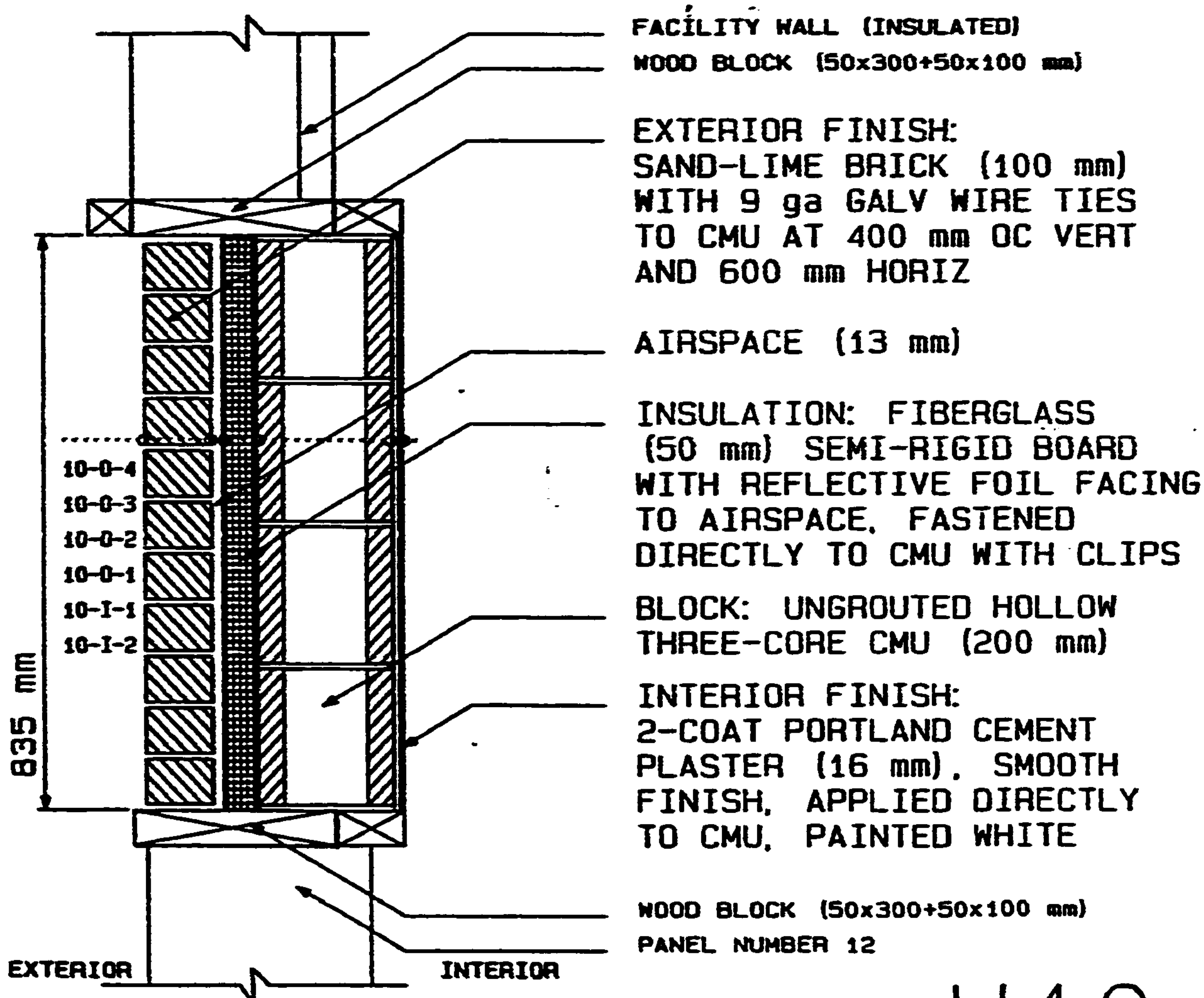
WALL PANEL SECTION 1: 10

W8



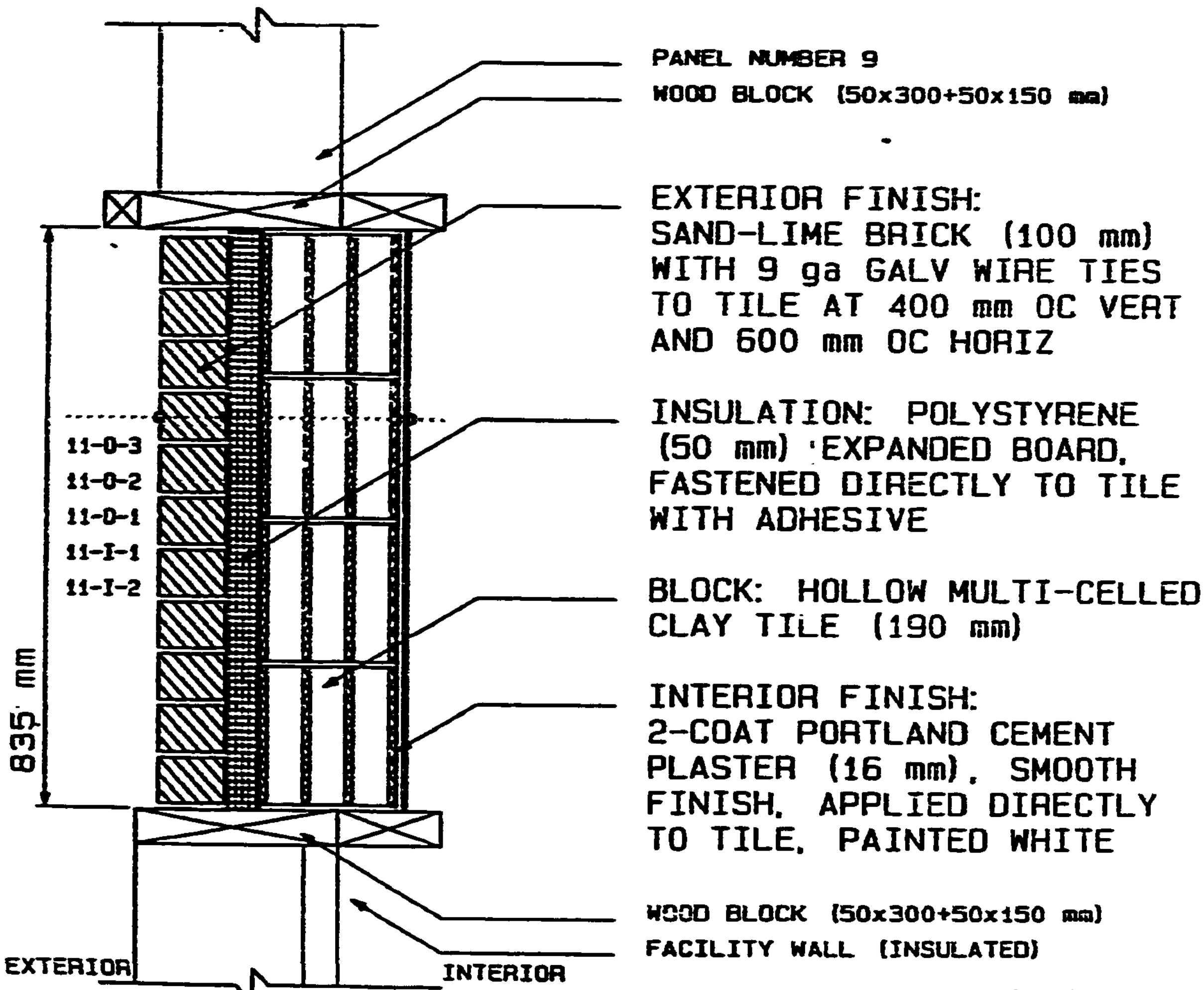
WALL PANEL SECTION 1: 10

W9



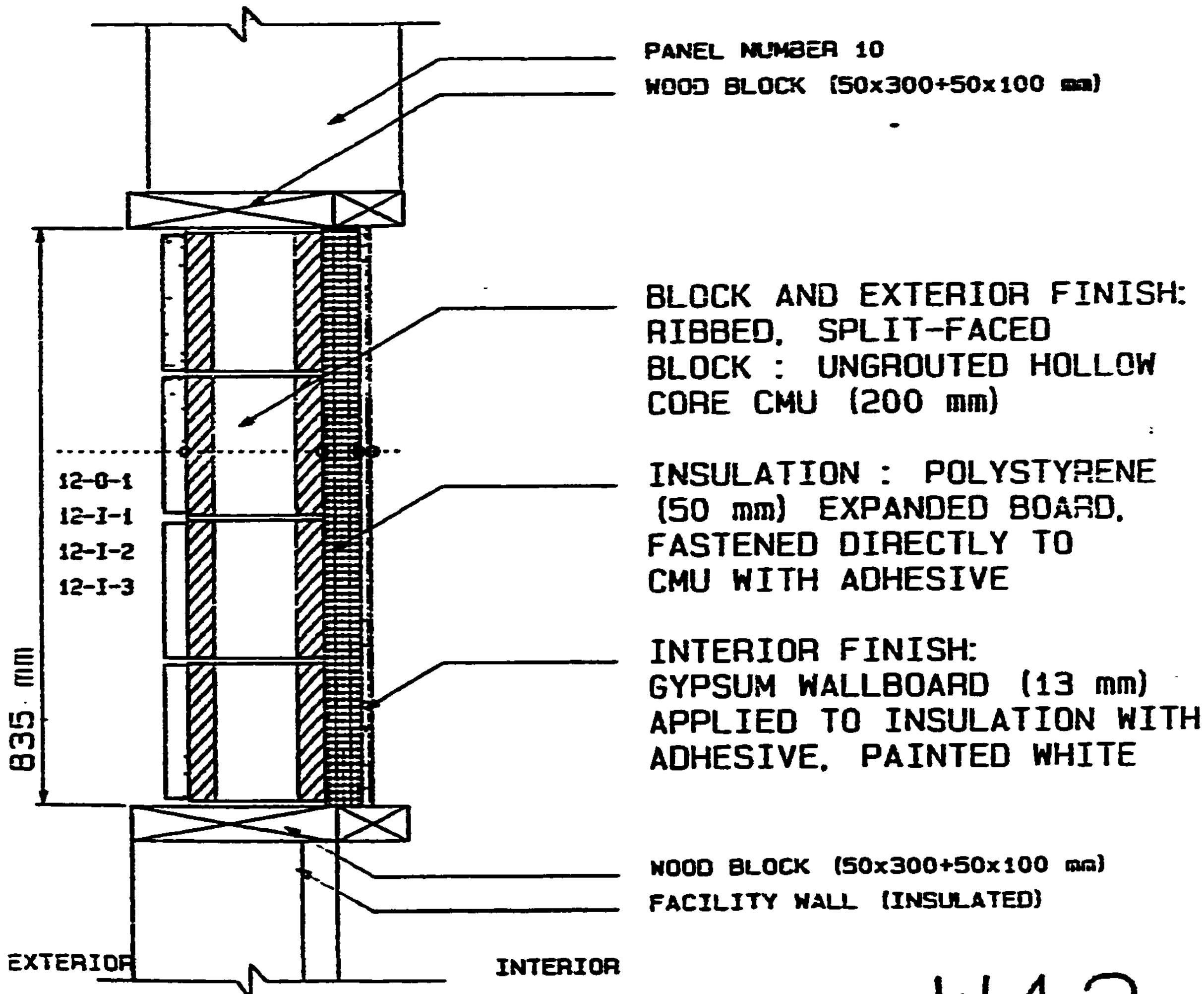
WALL PANEL SECTION 1: 10

W10



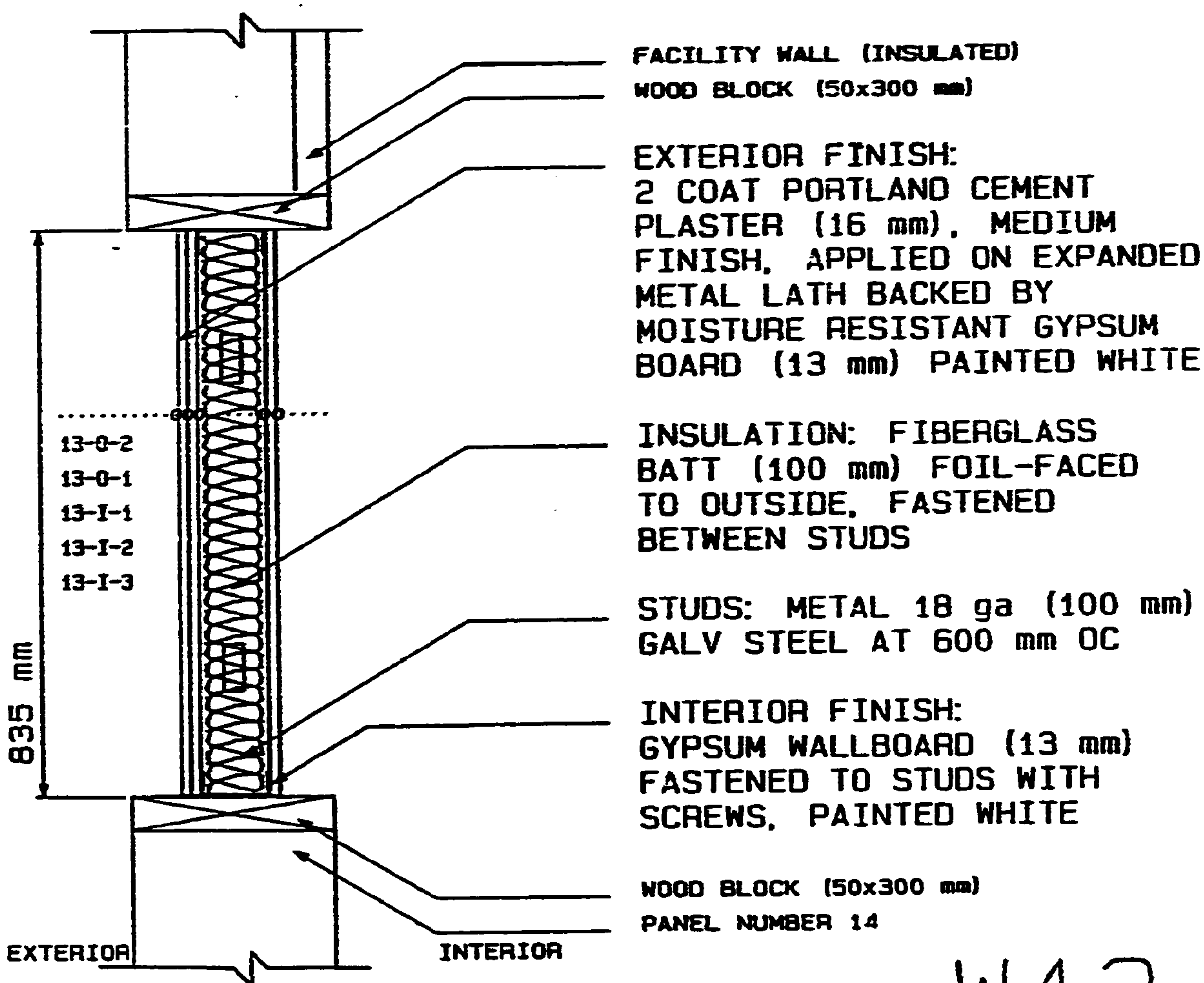
WALL PANEL SECTION 1: 10

W11



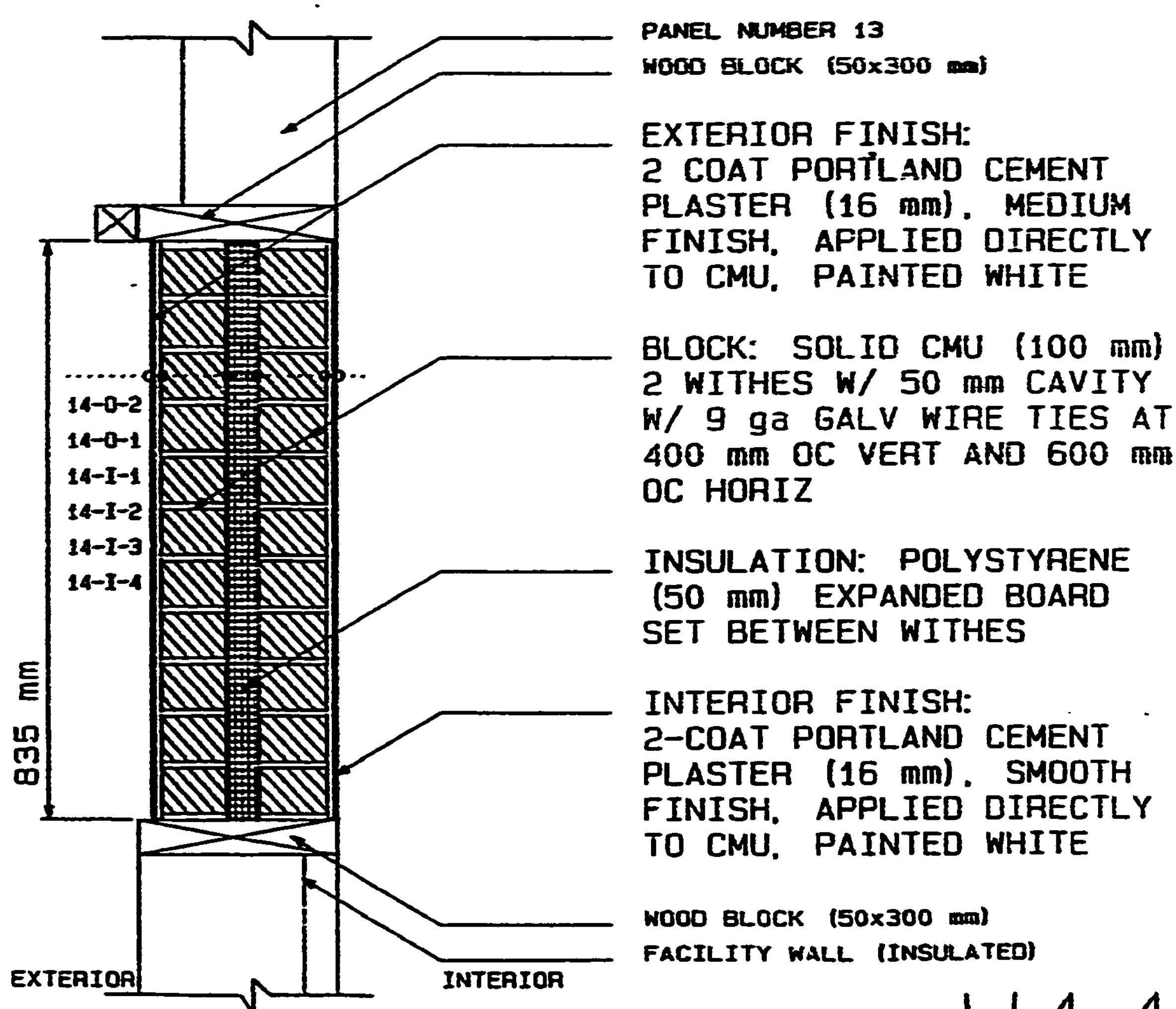
WALL PANEL SECTION 1: 10

W12



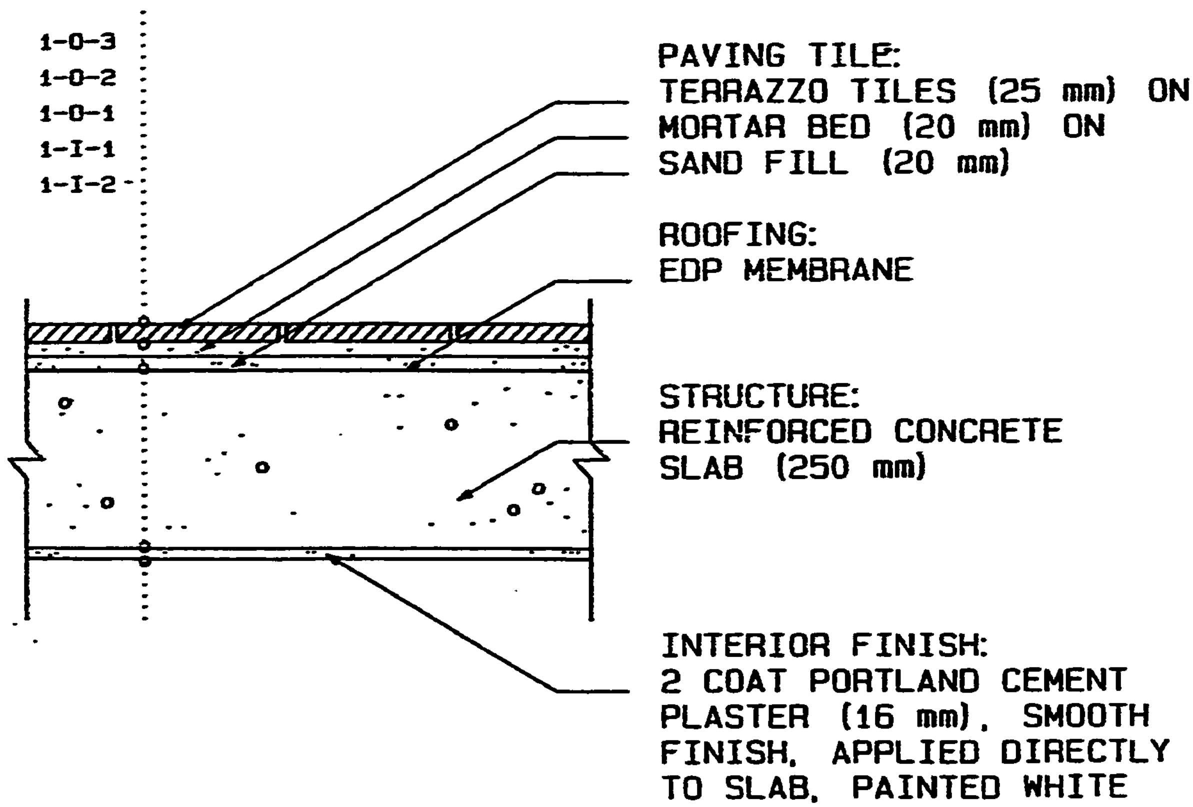
WALL PANEL SECTION 1: 10

W13



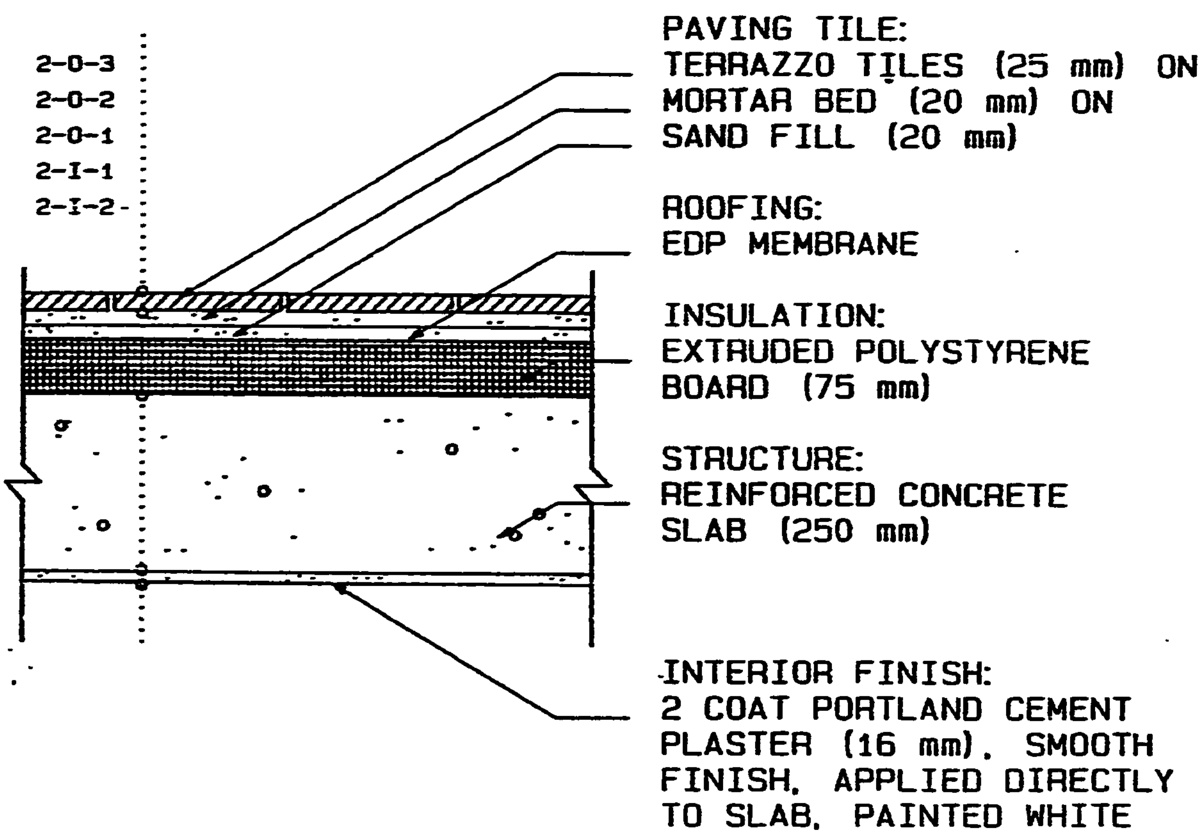
WALL PANEL SECTION 1: 10

W14



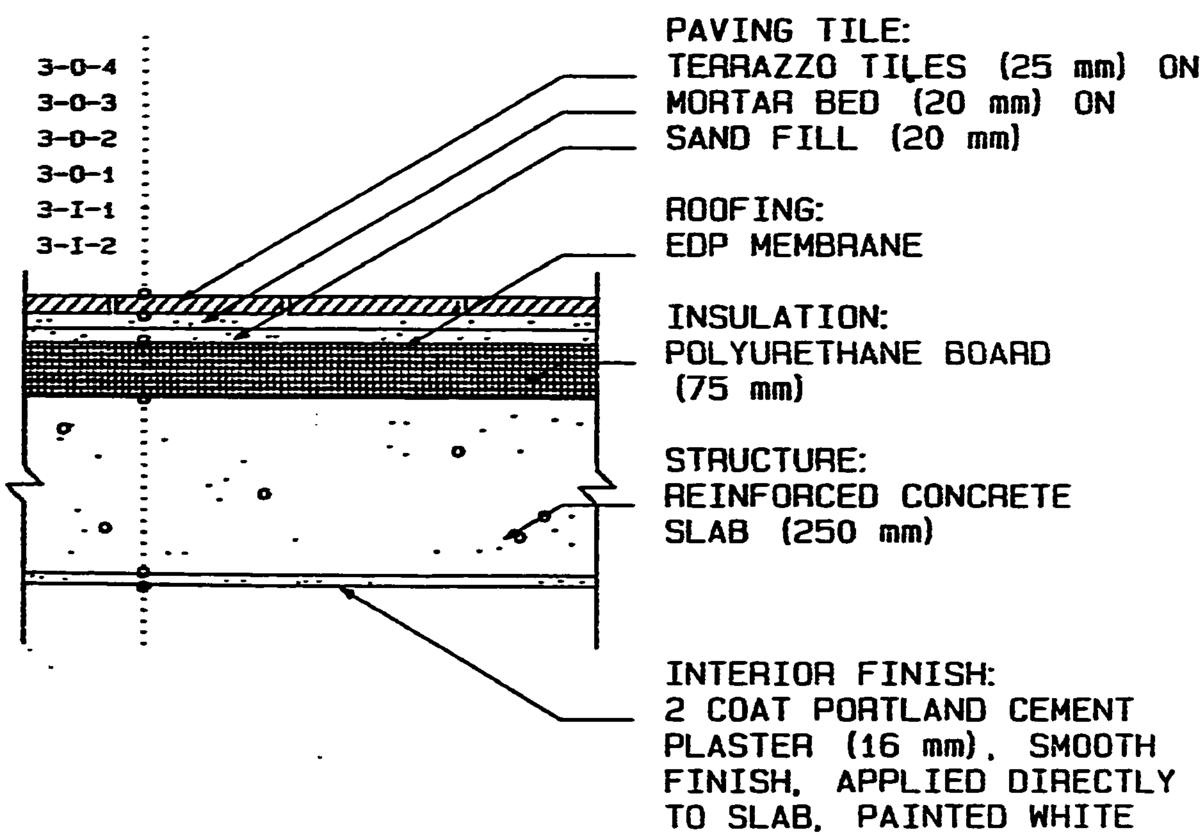
ROOF PANEL SECTION 1: 10

R1



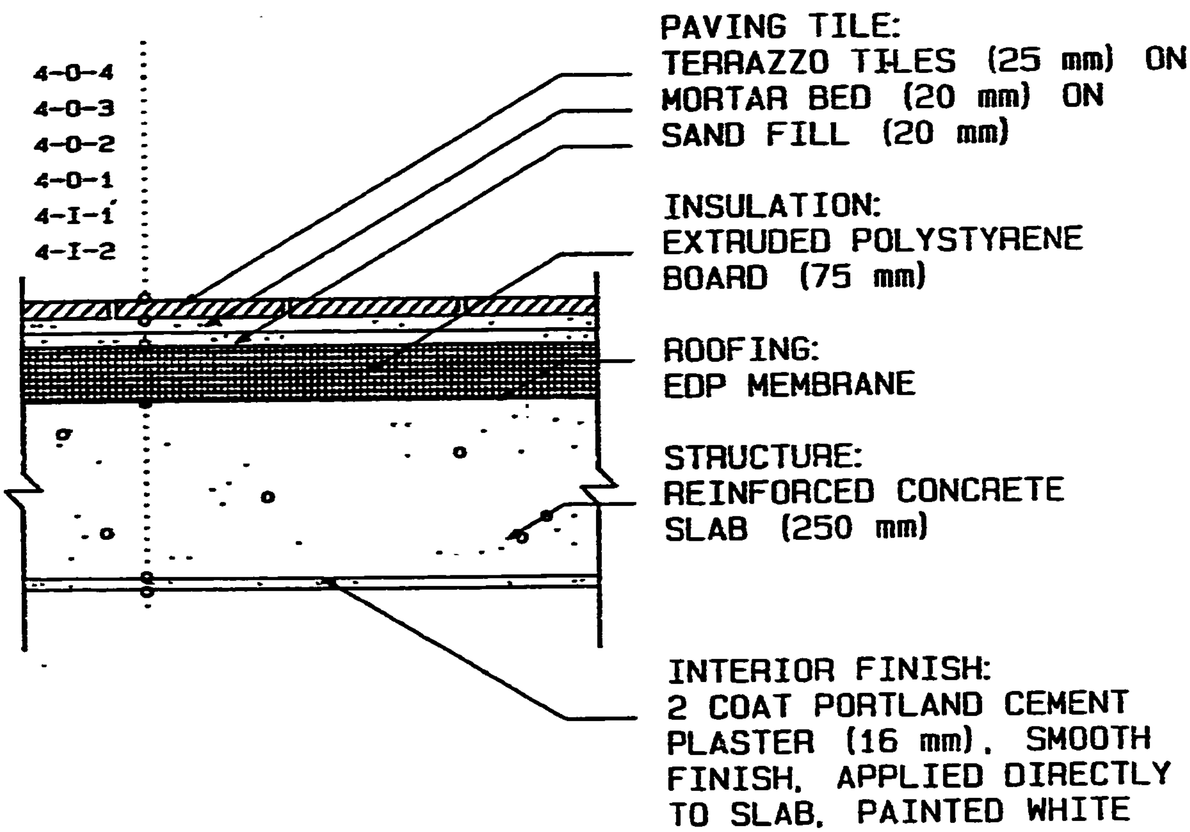
ROOF PANEL SECTION 1: 10

R2



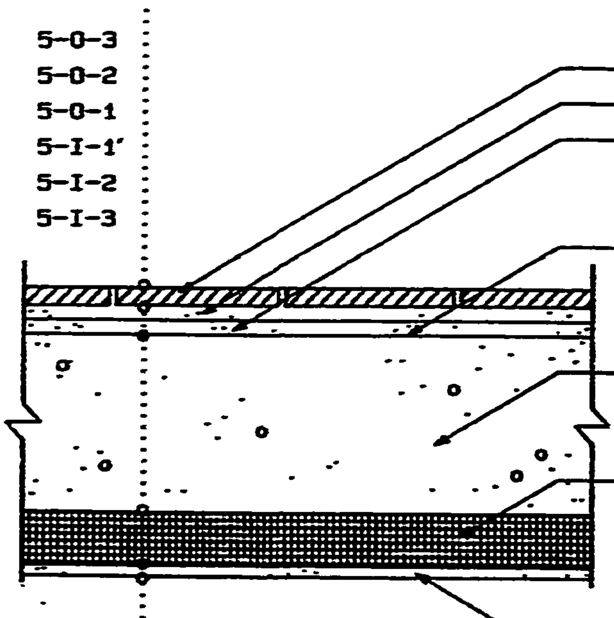
ROOF PANEL SECTION 1: 10

R3



ROOF PANEL SECTION 1: 10

R4



PAVING TILE:
TERRAZZO TILES (25 mm) ON
MORTAR BED (20 mm) ON
SAND FILL (20 mm)

ROOFING:
EDP MEMBRANE

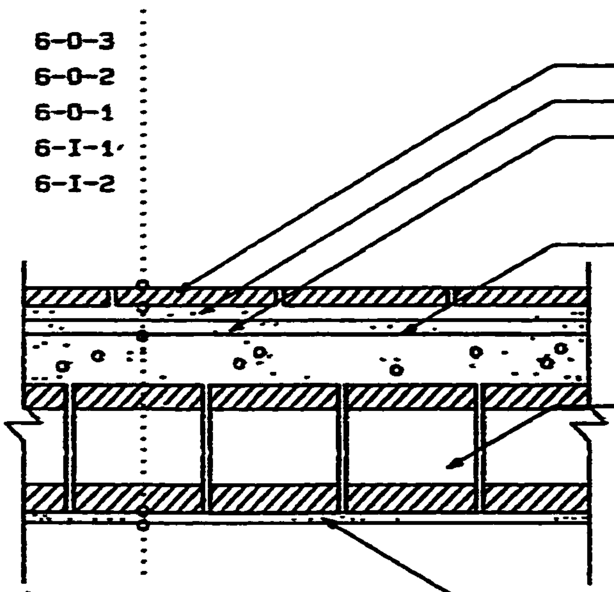
STRUCTURE:
REINFORCED CONCRETE
SLAB (250 mm)

INSULATION:
EXTRUDED POLYSTYRENE
(75mm)

INTERIOR FINISH:
2 COAT PORTLAND CEMENT
PLASTER (16 mm), SMOOTH
FINISH, APPLIED ON
EXPANDED METAL LATH ON
24 ga METAL CHANNELS AT
600 mm OC FASTENED
TO SLAB, PAINTED WHITE

ROOF PANEL SECTION 1: 10

R5



PAVING TILE:
TERRAZZO TILES (25 mm) ON
MORTAR BED (20 mm) ON
SAND FILL (20 mm)

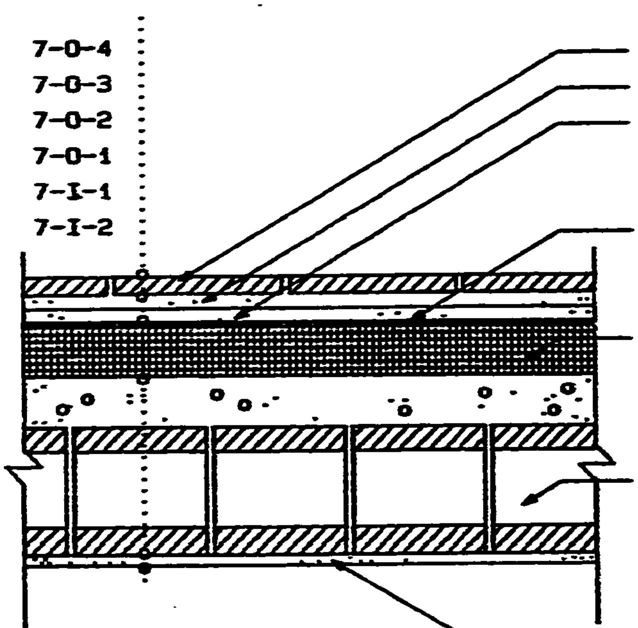
ROOFING:
EDP MEMBRANE

STRUCTURE:
REINFORCED CONCRETE
HOURDI SLAB (250 mm)
WITH CMU HOURDI BLOCK
(180 mm) AT 600 mm OC

INTERIOR FINISH:
2 COAT PORTLAND CEMENT
PLASTER (16 mm), SMOOTH
FINISH, APPLIED DIRECTLY
TO SLAB, PAINTED WHITE

ROOF PANEL SECTION 1: 10

R6



PAVING TILE:
TERRAZZO TILES (25 mm) ON
MORTAR BED (20 mm) ON
SAND FILL (20 mm)

ROOFING:
EDP MEMBRANE

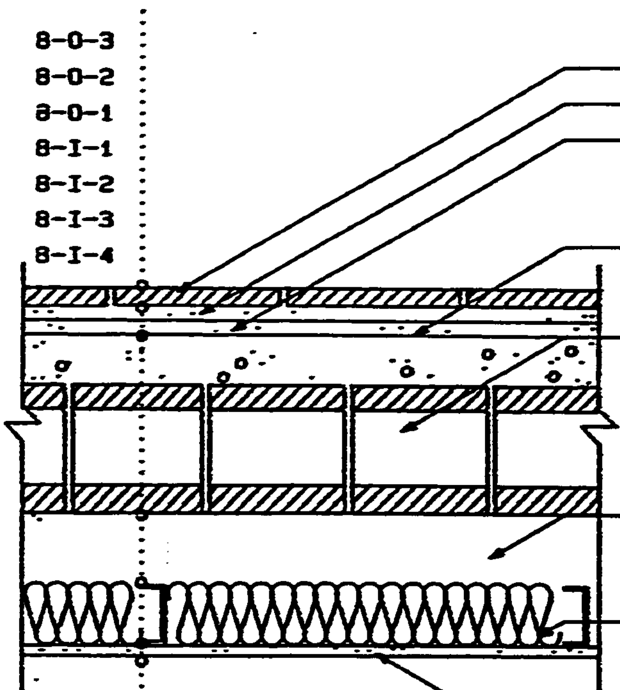
INSULATION:
EXTRUDED POLYSTYRENE
BOARD (75 mm)

STRUCTURE:
REINFORCED CONCRETE
HOURDI SLAB (250 mm)
WITH CMU HOURDI BLOCK
(180 mm) AT 600 mm OC

INTERIOR FINISH:
2 COAT PORTLAND CEMENT
PLASTER (16 mm), SMOOTH
FINISH, APPLIED DIRECTLY
TO SLAB, PAINTED WHITE

ROOF PANEL SECTION 1: 10

R7



PAVING TILE:
TERRAZZO TILES (25 mm) ON
MORTAR BED - (20 mm) ON
SAND FILL (20 mm)

ROOFING:
EDP MEMBRANE

STRUCTURE:
REINFORCED CONCRETE
HOURDI SLAB (250 mm)
WITH CMU HOURDI BLOCKS
(180 mm) AT 600 mm OC

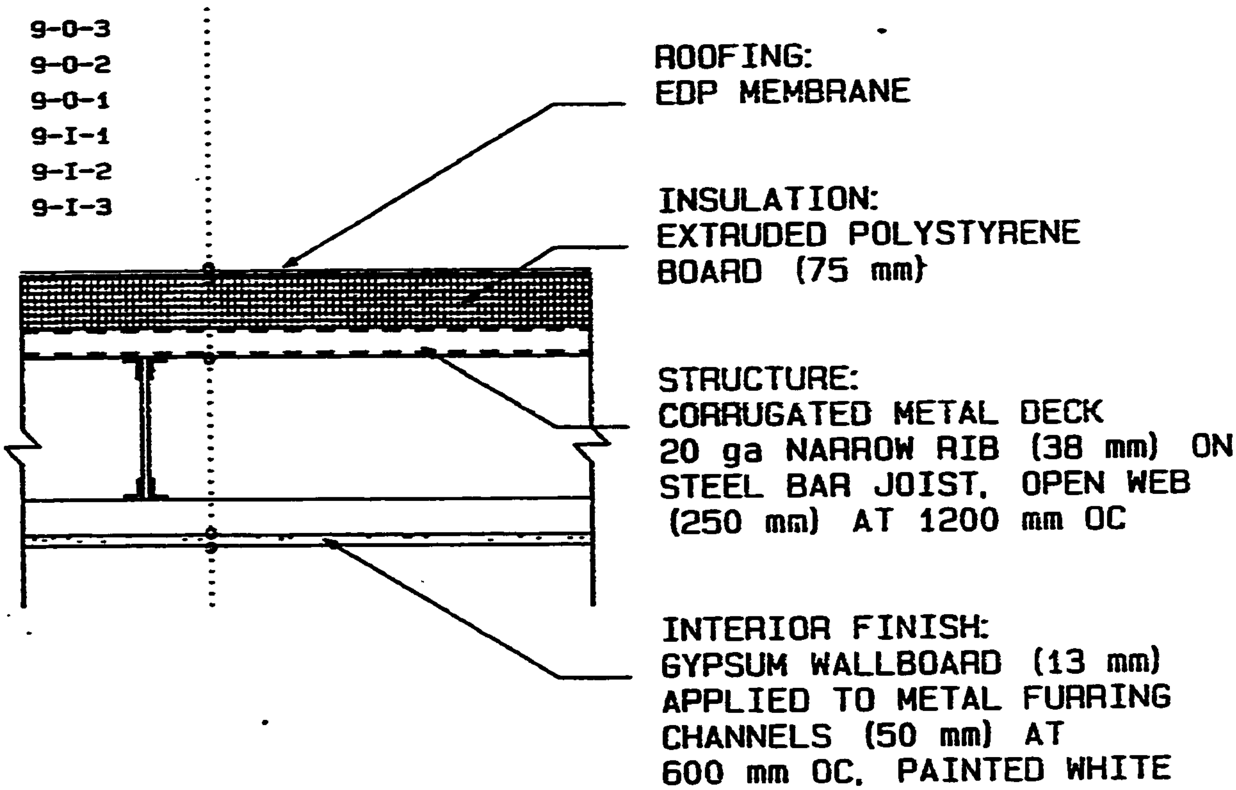
AIRSPACE: (100 mm)

INSULATION:
FIBERGLASS BATT (100 mm)
PAPER-FACED TO INSIDE

INTERIOR FINISH:
2 COAT PORTLAND CEMENT
PLASTER (16 mm), SMOOTH
FINISH, APPLIED ON EXPANDED
METAL LATH ON 24 ga METAL
CHANNELS AT 600 mm OC
FASTENED TO SLAB, PTD WHITE

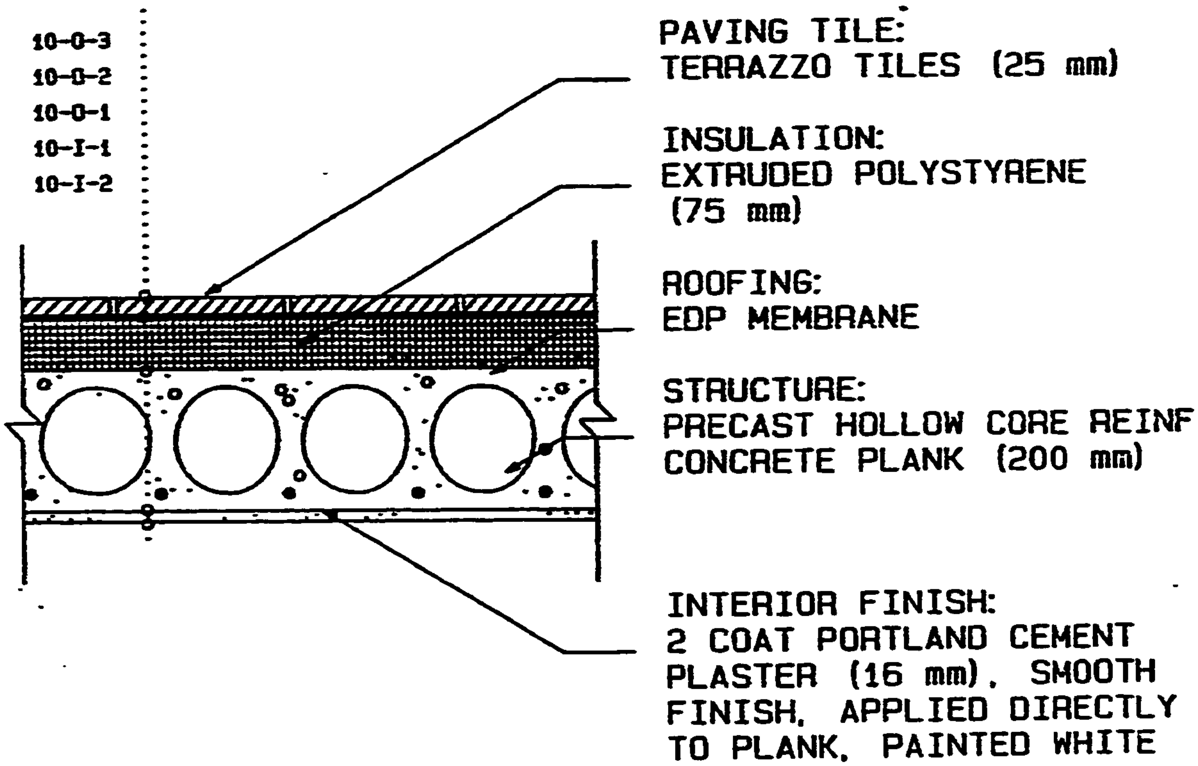
ROOF PANEL SECTION 1: 10

R8



ROOF PANEL SECTION 1: 10

R9



ROOF PANEL SECTION 1: 10

R10

Appendix D
Simulation Inputs

```
INPUT LOADS          INPUT-UNITS=ENGLISH
                     OUTPUT-UNITS=ENGLISH ..

TITLE                LINE-1     * VW11R28D *
                     LINE-2     * VILLA, WALL 1-1, ROOF 2-8, DHAHRAN* ..

ABORT                ERRORS ..
DIAGNOSTIC           WARNINGS ..

RUN-PERIOD           JAN 1 1989 THRU DEC 31 1989 ..

BUILDING-LOCATION $ FOR DHAHRAN RUNS
                     ALTITUDE=80
                     $ FOR RIYADH RUNS
                     $LTITUDE=1230
                     $ FOR JEDDAH RUNS
                     $LTITUDE=20
                     $ FOR KHAMIS-MUSHAYT RUNS
                     $LTITUDE=3000
                     HOLIDAY=NO
                     DAYLIGHT-SAVINGS=NO
                     AZIMUTH=0  ..

LOADS-REPORT         $ VERIFICATION FOR FIRST RUN ONLY IN 4-CITY SET (D)
                     $ERIFICATION=(LV-A,LV-B,LV-C,LV-D,LV-G,LV-H,LV-I,LV-J)
                     $ VERIFICATION FOR OTHER RUNS IN 4-CITY SET (R, J, K
                     VERIFICATION=(LV-A,LV-D)
                     $ SUMMARY FOR ALL RUNS
                     SUMMARY=(LS-A,LS-C,LS-D,LS-F) ..

                                $ NOTE 16 LAYERS MAX PER RUN
                                $ NOTE 32 CONSTRUCTIONS MAX PER RUN

                                $ MATERIALS

$ 13 MM PORTLAND CEMENT PLASTER
    M1               =MATERIAL
                     TH=0.043  COND=0.4167  DENS=116.  S-H=0.20  ..
$ M1 APPLIED TO METAL LATH
$   M1A              =MATERIAL
$                    TH=0.043  COND=0.430   DENS=116.  S-H=0.20  ..
$ 16 MM PORTLAND CEMENT STUCCO
    M2               =MATERIAL
                     TH=0.052  COND=0.4167  DENS=116.  S-H=0.20  ..
$ M2 APPLIED TO METAL LATH
$   M2A              =MATERIAL
$                    TH=0.052  COND=0.430   DENS=116.  S-H=0.20  ..
$ 200 MM 3-CORE CMU
    M3               =MATERIAL
                     TH=0.667  COND=0.606   DENS= 69.  S-H=0.20  ..
$ M3 WITH VERMICULITE FILL
$   M4               =MATERIAL
```

```
$                        TH=0.667  COND=0.2272  DENS= 70.  S-H=0.20  ..
$ 200 MM 3-CORE RIB SPLIT FACE CMU
$   M5                   =MATERIAL
$                        TH=0.750  COND=0.606   DENS= 69.  S-H=0.20  ..
$ 100 MM SOLID CMU
$   M6                   =MATERIAL
$                        TH=0.333  COND=0.4594  DENS=101.  S-H=0.20  ..
$ 200 MM HOLLOW CLAY TILE
$   M7                   =MATERIAL
$                        TH=0.667  COND=0.360   DENS= 70.  S-H=0.20  ..
$ 100 MM SAND-LIME BRICK
$   M8                   =MATERIAL
$                        TH=0.333  COND=0.318   DENS=104.  S-H=0.20  ..
$ 250 MM REINF CONC SLAB
    M9                   =MATERIAL
                         TH=0.820  COND=1.0417  DENS=140.  S-H=0.20  ..
$ 250 MM HOURDI BLOCK SLAB
$   M10                  =MATERIAL
$                        TH=0.820  COND=0.861   DENS=110.  S-H=0.20  ..
$ 200 MM PRECAST CORED PLANK
$   M11                  =MATERIAL
$                        TH=0.667  COND=0.758   DENS= 81.  S-H=0.20  ..
$ 25 MM TERRAZZO PAVING TILE
    M12                  =MATERIAL
                         TH=0.082  COND=1.0416  DENS=140.  S-H=0.19  ..
$ 20 MM MARBLE FACING TILE
$   M13                  =MATERIAL
$                        TH=0.066  COND=1.50    DENS=162.  S-H=0.21  ..
$ 20 MM MORTAR BED
    M14                  =MATERIAL
                         TH=0.066  COND=0.4167  DENS=116.  S-H=0.20  ..
$ 20 MM SAND FILL
    M15                  =MATERIAL
                         TH=0.066  COND=0.190   DENS= 94.6 S-H=0.191 ..
$ 250 MM LIGHTWEIGHT CONCRETE
$   M16                  =MATERIAL
$                        TH=0.820  COND=0.2083  DENS= 80.  S-H=0.20  ..
$ 13 MM GYPSUM WALLBOARD
$   P1                   =MATERIAL
$                        TH=0.043  COND=0.0926  DENS= 50.0 S-H=0.20  ..
$ 20 GA CORRUGATED METAL DECKING
$   P2                   =MATERIAL
$                        TH=0.003  COND=26.20   DENS=489.0 S-H=0.12  ..
$ 25 MM EXPANDED POLYSTYRENE BOARD
$   I1                   =MATERIAL
$                        TH=0.082  COND=0.021   DENS=  1.3 S-H=0.29  ..
$ 50 MM EXPANDED POLYSTYRENE BOARD
$   I2                   =MATERIAL
$                        TH=0.164  COND=0.021   DENS=  1.3 S-H=0.29  ..
$ 75 MM EXPANDED POLYSTYRENE BOARD
$   I3                   =MATERIAL
$                        TH=0.246  COND=0.021   DENS=  1.3 S-H=0.29  ..
$ 100 MM EXPANDED POLYSTYRENE BOARD
    I3A                  =MATERIAL
```

```
                        TH=0.328  COND=0.021   DENS=  1.3 S-H=0.29  ..
$ 25 MM EXTRUDED POLYSTYRENE BOARD
$   I4                  =MATERIAL
$                       TH=0.082  COND=0.0183  DENS=  1.31  S-H=0.29  ..
$ 50 MM EXTRUDED POLYSTYRENE BOARD
$   I5                  =MATERIAL
$                       TH=0.164  COND=0.0183  DENS=  1.31  S-H=0.29  ..
$ 75 MM EXTRUDED POLYSTYRENE BOARD
$   I6                  =MATERIAL
$                       TH=0.246  COND=0.0183  DENS=  1.31  S-H=0.29  ..
$ 100 MM EXTRUDED POLYSTYRENE BOARD
$   I7                  =MATERIAL
$                       TH=0.328  COND=0.0183  DENS=  1.31  S-H=0.29  ..
$ 25 MM POLYURETHANE BOARD
$   I8                  =MATERIAL
$                       TH=0.082  COND=0.0136  DENS=  2.19  S-H=0.38  ..
$ 50 MM POLYURETHANE BOARD
$   I9                  =MATERIAL
$                       TH=0.164  COND=0.0136  DENS=  2.19  S-H=0.38  ..
$ 75 MM POLYURETHANE BOARD
$   I10                 =MATERIAL
$                       TH=0.246  COND=0.0136  DENS=  2.19  S-H=0.38  ..
$ 100 MM POLYURETHANE BOARD
$   I10A                =MATERIAL
$                       TH=0.328  COND=0.0136  DENS=  2.19  S-H=0.38  ..
$ 25 MM GLASS FIBER BOARD
$   I11                 =MATERIAL
$                       TH=0.082  COND=0.0191  DENS=  3.0   S-H=0.23  ..
$.50 MM GLASS FIBER BOARD
$   I12                 =MATERIAL
$                       TH=0.164  COND=0.0191  DENS=  3.0   S-H=0.23  ..
$ 75 MM GLASS FIBER BOARD
$   I13                 =MATERIAL
$                       TH=0.246  COND=0.0191  DENS=  3.0   S-H=0.23  ..
$ 100 MM GLASS FIBER BOARD
$   I13A                =MATERIAL
$                       TH=0.328  COND=0.0191  DENS=  3.0   S-H=0.23  ..
$ 75 MM GLASS FIBER BATT
$   I14                 =MATERIAL
$                       TH=0.246  COND=0.0266  DENS=   .63  S-H=0.20  ..
$ 100 MM GLASS FIBER BATT
$   I15                 =MATERIAL
$                       TH=0.328  COND=0.0266  DENS=   .63  S-H=0.20  ..
$ 150 MM GLASS FIBER BATT
$   I16                 =MATERIAL
$                       TH=0.492  COND=0.0266  DENS=   .63  S-H=0.20  ..
$ EDP WATERPROOFING MEMBRANE
    W1                  =MATERIAL
                        TH=0.003  COND=0.02    DENS= 70.0   S-H=0.36  ..
$ INSIDE AIR FILM VERTICAL
$   A2                  =MATERIAL
$                       RES=0.68 ..
$ INSIDE AIR FILM HORIZONTAL
$   A3                  =MATERIAL
```

```
$                      RES=0.92 ..
$ 13 MM AIR SPACE VERTICAL NON-REFLECTIVE
$   A4                 =MATERIAL
$                      RES=.077 ..
$ 13 MM AIR SPACE VERTICAL REFLECTIVE ONE SIDE
$   A4A                =MATERIAL
$                      RES=1.67 ..
$ 50 MM AIR SPACE VERTICAL
$   A5                 =MATERIAL
$                      RES=0.86 ..
$ 100 MM AIR SPACE HORIZONTAL
$   A6                 =MATERIAL
$                      RES=0.92 ..
$ 250 MM AIR SPACE HORIZONTAL
$   A7                 =MATERIAL
$                      RES=1.53 ..
$ 100 MM AIR SPACE VERTICAL
$   A8                 =MATERIAL
$                      RES=0.92 ..
$ 200 MM AIR SPACE HORIZONTAL
$   A9                 =MATERIAL
$                      RES=0.92 ..

                             $ LAYERS

    L-W1-1             =LAYERS
                       INSIDE-FILM-RES=0.68  MATERIAL=(M2,M3,M1) ..
$   L-W2-1             =LAYERS
$                      INSIDE-FILM-RES=0.68  MATERIAL=(M2,M3,I2,M1A) ..
$   L-W2-2             =LAYERS
$                      INSIDE-FILM-RES=0.68  MATERIAL=(M2,M3,I1,M1A) ..
$   L-W2-3             =LAYERS
$                      INSIDE-FILM-RES=0.68  MATERIAL=(M2,M3,I3,M1A) ..
$   L-W2-4             =LAYERS
$                      INSIDE-FILM-RES=0.68  MATERIAL=(M2,M3,I3A,M1A) ..
$   L-W3-1             =LAYERS
$                      INSIDE-FILM-RES=0.68  MATERIAL=(M2,M4,M1) ..
$   L-W4-1             =LAYERS
$                      INSIDE-FILM-RES=0.68  MATERIAL=(M2,M3,I12,M1A) ..
$   L-W4-2             =LAYERS
$                      INSIDE-FILM-RES=0.68  MATERIAL=(M2,M3,I11,M1A) ..
$   L-W4-3             =LAYERS
$                      INSIDE-FILM-RES=0.68  MATERIAL=(M2,M3,I13,M1A) ..
$   L-W4-4             =LAYERS
$                      INSIDE-FILM-RES=0.68  MATERIAL=(M2,M3,I13A,M1A) ..
$   L-W5-1             =LAYERS
$                      INSIDE-FILM-RES=0.68  MATERIAL=(M2A,I2,M3,M1) ..
$   L-W5-2             =LAYERS
$                      INSIDE-FILM-RES=0.68  MATERIAL=(M2A,I1,M3,M1) ..
$   L-W5-3             =LAYERS
$                      INSIDE-FILM-RES=0.68  MATERIAL=(M2A,I3,M3,M1) ..
$   L-W6-1             =LAYERS
$                      INSIDE-FILM-RES=0.68  MATERIAL=(M2A,I9,M3,M1) ..
$   L-W6-2             =LAYERS
```

```
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M2A,I8,M3,M1) ..
$   L-W6-3         =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M2A,I10,M3,M1) ..
$   L-W6-4         =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M2,M3,I9,M1A) ..
$   L-W6-5         =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M2,M3,I8,M1A) ..
$   L-W6-6         =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M2,M3,I10,M1A) ..
$   L-W6-7         =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M2,M3,I10A,M1A) ..
$   L-W7-1         =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M13,I2,M3,M1) ..
$   L-W7-2         =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M13,M3,I2,M1A) ..
$   L-W8-1         =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M8,I2,M3,M1) ..
$   L-W8-2         =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M8,M3,I2,M1A) ..
$   L-W8-3         =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M8,A4,M3,I2,M1A) ..
$   L-W9-1         =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M2A,I2,M7,M1) ..
$   L-W9-2         =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M2,M7,M1) ..
$   L-W9-3         =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M2,M7,I2,M1A) ..
$   L-W10-1        =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M8,A4A,I12,M3,M1) ..
$   L-W10-2        =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M8,A4,,M3,M1) ..
$   L-W10-3        =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M8,A4,M3,I12,M1A) ..
$   L-W10-4        =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M8,A4,I12,M3,M1) ..
$   L-W11-1        =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M8,I2,M7,M1A) ..
$   L-W11-2        =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M8,M7,M1) ..
$   L-W11-3        =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M8,M7,I2,M1A) ..
$   L-W12-1        =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M5,I2,M1A) ..
$   L-W12-2        =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M5,M1) ..
$   L-W13-1        =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M2A,P1,I14,P1) ..
$   L-W13-2        =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M2A,P1,I15,P1) ..
$   L-W13-3        =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M2A,P1,A8,P1) ..
$   L-W14-1        =LAYERS
$                  INSIDE-FILM-RES=0.68  MATERIAL=(M2,M6,I2,M6,M1) ..
$   L-W14-2        =LAYERS
```

```
$                   INSIDE-FILM-RES=0.68  MATERIAL=(M2,M6,A5,M6,M1) ..
$   L-WI4-3         =LAYERS
$                   INSIDE-FILM-RES=0.68  MATERIAL=(M2,M6,I1,M6,M1) ..
$   L-W14-4         =LAYERS
$                   INSIDE-FILM-RES=0.68  MATERIAL=(M2,M6,I3,M6,M1) ..

$   L-R1-1          =LAYERS
$                   INSIDE-FILM-RES=0.92  MATERIAL=(M12,M14,M15,W1,M9,M1) ..
$   L-R2-1          =LAYERS
$                   INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,W1,I6,M9,M1) ..
$   L-R2-2          =LAYERS
$                   INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,W1,I4,M9,M1) ..
$   L-R2-3          =LAYERS
$                   INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,W1,I5,M9,M1) ..
$   L-R2-4          =LAYERS
$                   INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,W1,I7,M9,M1) ..
$   L-R2-5          =LAYERS
$                   INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,W1,I3,M9,M1) ..
$   L-R2-6          =LAYERS
$                   INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,W1,I1,M9,M1) ..
$   L-R2-7          =LAYERS
$                   INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,W1,I2,M9,M1) ..
    L-R2-8          =LAYERS
                   INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,W1,I3A,M9,M1) ..
$   L-R3-1          =LAYERS
$                   INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,W1,I10,M9,M1) ..
$   L-R4-1          =LAYERS
$                   INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,I6,W1,M9,M1) ..
$   L-R4-2          =LAYERS
$                   INSIDE-FILM-RES=0.92  MAT=(M12,M15,I6,W1,M9,M1) ..
$   L-R4-3          =LAYERS
$                   INSIDE-FILM-RES=0.92  MAT=(M12,I6,W1,M9,M1) ..
$   L-R5-1          =LAYERS
$                   INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,W1,M9,I6,M1A) ..
$   L-R5-2          =LAYERS
$                   INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,W1,M9,I4,M1A) ..
$   L-R5-3          =LAYERS
$                   INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,W1,M9,I5,M1A) ..
$   L-R5-4          =LAYERS
$                   INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,W1,M9,I7,M1A) ..
$   L-R6-1          =LAYERS
$                    INSIDE-FILM-RES=0.92   MATERIAL=(M12,M14,M15,W1,M10,M1)
..
$   L-R7-1          =LAYERS
$                   INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,W1,I3,M10,M1) ..
$   L-R7-2          =LAYERS
$                   INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,W1,I1,M10,M1) ..
$   L-R7-3          =LAYERS
$                   INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,W1,I2,M10,M1) ..
$   L-R7-4          =LAYERS
$                  INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,W1,I3A,M10,M1) ...
$   L-R8-1          =LAYERS
$                   I-F-R=0.92  MAT=(M12,M14,M15,W1,M10,A6,I15,M1A) ..
$   L-R8-2          =LAYERS
```

```
$                       I-F-R=0.92  MAT=(M12,M14,M15,W1,M10,A6,I14,M1A) ..
$      L-R8-3           =LAYERS
$                       I-F-R=0.92  MAT=(M12,M14,M15,W1,M10,A6,I16,M1A) ..
$      L-R8-4           =LAYERS
$                       I-F-R=0.92  MAT=(M12,M14,M15,W1,M10,A9,M1A) ..
$      L-R9-1           =LAYERS
$                       INSIDE-FILM-RES=0.92  MAT=(W1,I6,P2,A7,P1) ..
$      L-R9-2           =LAYERS
$                       INSIDE-FILM-RES=0.92  MAT=(W1,I7,P2,A7,P1) ..
$      L-R9-3           =LAYERS
$                       INSIDE-FILM-RES=0.92  MAT=(W1,P2,A7,P1) ..
$      L-R10-1          =LAYERS
$                       INSIDE-FILM-RES=0.92  MAT=(M12,I6,W1,M11,M1) ..
$      L-R10-2          =LAYERS
$                       INSIDE-FILM-RES=0.92  MAT=(M12,W1,M11,M1) ..
$      L-R10-3          =LAYERS
$                       INSIDE-FILM-RES=0.92  MAT=(M12,I5,W1,M11,M1) ..
$      L-R11-1          =LAYERS
$                       INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,W1,I6,M16,M1)..
$      L-R11-2          =LAYERS
$                       INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,W1,M16,M1) ..
$      L-R11-3          =LAYERS
$                       INSIDE-FILM-RES=0.92  MAT=(M12,M14,M15,W1,I5,M16,M1)..

                                  $ CONSTRUCTIONS

       W1-1             =CONSTRUCTION
                        LAYERS=L-W1-1   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$      W2-1             =CONSTRUCTION
$                       LAYERS=L-W2-1   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$      W2-2             =CONSTRUCTION
$                       LAYERS=L-W2-2   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$      W2-3             =CONSTRUCTION
$                       LAYERS=L-W2-3   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$      W2-4             =CONSTRUCTION
$                       LAYERS=L-W2-4   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$      W3-1             =CONSTRUCTION
$                       LAYERS=L-W3-1   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$      W4-1             =CONSTRUCTION
$                       LAYERS=L-W4-1   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$      W4-2             =CONSTRUCTION
$                       LAYERS=L-W4-2   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$      W4-3             =CONSTRUCTION
$                       LAYERS=L-W4-3   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$      W4-4             =CONSTRUCTION
$                       LAYERS=L-W4-4   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$      W5-1             =CONSTRUCTION
$                       LAYERS=L-W5-1   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$      W5-2             =CONSTRUCTION
$                       LAYERS=L-W5-2   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$      W5-3             =CONSTRUCTION
$                       LAYERS=L-W5-3   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$      W6-1             =CONSTRUCTION
$                       LAYERS=L-W6-1   ABSORPTANCE=0.4  ROUGHNESS=3 ..
```

```
$   W6-2    =CONSTRUCTION
$           LAYERS=L-W6-2   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W6-3    =CONSTRUCTION
$           LAYERS=L-W6-3   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W6-4    =CONSTRUCTION
$           LAYERS=L-W6-4   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W6-5    =CONSTRUCTION
$           LAYERS=L-W6-5   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W6-6    =CONSTRUCTION
$           LAYERS=L-W6-6   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W6-7    =CONSTRUCTION
$           LAYERS=L-W6-7   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W7-1    =CONSTRUCTION
$           LAYERS=L-W7-1   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W7-2    =CONSTRUCTION
$           LAYERS=L-W7-2   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W8-1    =CONSTRUCTION
$           LAYERS=L-W8-1   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W8-2    =CONSTRUCTION
$           LAYERS=L-W8-2   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W8-3    =CONSTRUCTION
$           LAYERS=L-W8-3   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W9-1    =CONSTRUCTION
$           LAYERS=L-W9-1   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W9-2    =CONSTRUCTION
$           LAYERS=L-W9-2   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W9-3    =CONSTRUCTION
$           LAYERS=L-W9-3   ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W10-1   =CONSTRUCTION
$           LAYERS=L-W10-1  ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W10-2   =CONSTRUCTION
$           LAYERS=L-W10-2  ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W10-3   =CONSTRUCTION
$           LAYERS=L-W10-3  ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W10-4   =CONSTRUCTION
$           LAYERS=L-W10-3  ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W11-1   =CONSTRUCTION
$           LAYERS=L-W11-1  ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W11-2   =CONSTRUCTION
$           LAYERS=L-W11-2  ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W11-3   =CONSTRUCTION
$           LAYERS=L-W11-3  ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W12-1   =CONSTRUCTION
$           LAYERS=L-W12-1  ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W12-2   =CONSTRUCTION
$           LAYERS=L-W12-2  ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W13-1   =CONSTRUCTION
$           LAYERS=L-W13-1  ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W13-2   =CONSTRUCTION
$           LAYERS=L-W13-2  ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W13-3   =CONSTRUCTION
$           LAYERS=L-W13-3  ABSORPTANCE=0.4  ROUGHNESS=3 ..
$   W14-1   =CONSTRUCTION
$           LAYERS=L-W14-1  ABSORPTANCE=0.4  ROUGHNESS=3 ..
```

```
$   W14-2        =CONSTRUCTION
$               LAYERS=L-W14-2   ABSORPTANCE=0.4   ROUGHNESS=3 ..
$   W14-3        =CONSTRUCTION
$               LAYERS=L-W14-3   ABSORPTANCE=0.4   ROUGHNESS=3 ..
$   W14-4        =CONSTRUCTION
$               LAYERS=L-W14-4   ABSORPTANCE=0.4   ROUGHNESS=3 ..

$   R1-1        =CONSTRUCTION
$               LAYERS=L-R1-1    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R2-1        =CONSTRUCTION
$               LAYERS=L-R2-1    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R2-2        =CONSTRUCTION
$               LAYERS=L-R2-2    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R2-3        =CONSTRUCTION
$               LAYERS=L-R2-3    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R2-4        =CONSTRUCTION
$               LAYERS=L-R2-4    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R2-5        =CONSTRUCTION
$               LAYERS=L-R2-5    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R2-6        =CONSTRUCTION
$               LAYERS=L-R2-6    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R2-7        =CONSTRUCTION
$               LAYERS=L-R2-7    ABSORPTANCE=0.5   ROUGHNESS=3 ..
    R2-8        =CONSTRUCTION
                LAYERS=L-R2-8    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R3-1        =CONSTRUCTION
$               LAYERS=L-R3-1    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R4-1        =CONSTRUCTION
$               LAYERS=L-R4-1    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R4-2        =CONSTRUCTION
$               LAYERS=L-R4-2    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R4-3        =CONSTRUCTION
$               LAYERS=L-R4-3    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R5-1        =CONSTRUCTION
$               LAYERS=L-R5-1    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R5-2        =CONSTRUCTION
$               LAYERS=L-R5-2    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R5-3        =CONSTRUCTION
$               LAYERS=L-R5-3    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R5-4        =CONSTRUCTION
$               LAYERS=L-R5-4    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R6-1        =CONSTRUCTION
$               LAYERS=L-R6-1    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R7-1        =CONSTRUCTION
$               LAYERS=L-R7-1    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R7-2        =CONSTRUCTION
$               LAYERS=L-R7-2    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R7-3        =CONSTRUCTION
$               LAYERS=L-R7-3    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R7-4        =CONSTRUCTION
$               LAYERS=L-R7-4    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R8-1        =CONSTRUCTION
$               LAYERS=L-R8-1    ABSORPTANCE=0.5   ROUGHNESS=3 ..
$   R8-2        =CONSTRUCTION
```

```
$                    LAYERS=L-R8-2     ABSORPTANCE=0.5  ROUGHNESS=3 ..
$   R8-3             =CONSTRUCTION
$                    LAYERS=L-R8-3     ABSORPTANCE=0.5  ROUGHNESS=3 ..
$   R8-4             =CONSTRUCTION
$                    LAYERS=L-R8-4     ABSORPTANCE=0.5  ROUGHNESS=3 ..
$   R9-1             =CONSTRUCTION
$                    LAYERS=L-R9-1     ABSORPTANCE=0.5  ROUGHNESS=3 ..
$   R9-2             =CONSTRUCTION
$                    LAYERS=L-R9-2     ABSORPTANCE=0.5  ROUGHNESS=3 ..
$   R9-3             =CONSTRUCTION
$                    LAYERS=L-R9-3     ABSORPTANCE=0.5  ROUGHNESS=3 ..
$   R10-1            =CONSTRUCTION
$                    LAYERS=L-R10-1    ABSORPTANCE=0.5  ROUGHNESS=3 ..
$   R10-2            =CONSTRUCTION
$                    LAYERS=L-R10-2    ABSORPTANCE=0.5  ROUGHNESS=3 ..
$   R10-3            =CONSTRUCTION
$                    LAYERS=L-R10-3    ABSORPTANCE=0.5  ROUGHNESS=3 ..
$   R11-1            =CONSTRUCTION
$                    LAYERS=L-R11-1    ABSORPTANCE=0.5  ROUGHNESS=3 ..
$   R11-2            =CONSTRUCTION
$                    LAYERS=L-R11-2    ABSORPTANCE=0.5  ROUGHNESS=3 ..
$   R11-3            =CONSTRUCTION
$                    LAYERS=L-R11-3    ABSORPTANCE=0.5  ROUGHNESS=3 ..
    GLASS-1          =GLASS-TYPE
                     PANES=1  SHADING-COEF=0.6            ..
    DOOR-1           =CONSTRUCTION
                     U-VALUE=0.50      ABSORPTANCE=0.78 ROUGHNESS=4 ..

                              $ OCCUPANCY, LIGHTING, AND
                              $ EQUIPMENT SCHEDULES

    OCC-WD-V         =DAY-SCHEDULE   (1,7) (0.90)
                                     (8,12) (0.5)
                                     (13,17) (0.75)
                                     (18,24) (1.0)  ..
    OCC-WE-V         =DAY-SCHEDULE   (1,8) (0.90)
                                     (9,21) (0.5)
                                     (22,24) (1.0)  ..
    OCC-WEEK-V       =WEEK-SCHEDULE  (MON,WED) OCC-WD-V (THU,FRI) OCC-WE-V
                                     (SAT,SUN) OCC-WD-V (HOL) OCC-WE-V  ..
    PEOPLE-V         =SCHEDULE       THRU DEC 31 OCC-WEEK-V  ..
    LTS-WD-V         =DAY-SCHEDULE   (1,5) (0.05)
                                     (6,9) (0.5)
                                     (10,17) (0.25)
                                     (18,20) (1.0)
                                     (21,23) (0.75)
                                     (24) (0.5)  ..
    LTS-WE-V         =DAY-SCHEDULE   (1,6) (0.05)
                                     (7,17) (0.4)
```

```
                 (18,24) (1.0)  ..

LTS-WEEK-V    =WEEK-SCHEDULE (MON,WED) LTS-WD-V (THU,FRI) LTS-WE-V
                             (SAT,SUN) LTS-WD-V (HOL) LTS-WE-V  ..

LIGHTS-V      =SCHEDULE      THRU DEC 31 LTS-WEEK-V  ..

EQP-WD-V      =DAY-SCHEDULE  (1,5) (0.0)
                             (6,17) (0.5)
                             (18,22) (1.0)
                             (23,24) (0.3) ..

EQP-WE-V      =DAY-SCHEDULE  (1,6) (0.0)
                             (7,17) (0.7)
                             (18,24) (1.0)  ..

EQP-WEEK-V    =WEEK-SCHEDULE (MON,WED) EQP-WD-V (THU,FRI) EQP-WE-V
                             (SAT,SUN) EQP-WD-V (HOL) EQP-WE-V  ..

EQUIPS-V      =SCHEDULE      THRU DEC 31 EQP-WEEK-V  ..

INFILT-V      =SCHEDULE      THRU DEC 31 (ALL) (1,24) (1.0)  ..

                        $ BUILDING SPACES--TYPICAL VILLA

TWO-FLOORS-V  =SPACE
              AREA=5070
              VOLUME=49432
              SHAPE=BOX
              WIDTH=52.0
              DEPTH=48.0
              HEIGHT=19.5
              PEOPLE-SCHEDULE=PEOPLE-V
              LIGHTING-SCHEDULE=LIGHTS-V
              EQUIP-SCHEDULE=EQUIPS-V
              INF-SCHEDULE=INFILT-V
              INF-METHOD=RESIDENTIAL
              NUMBER-OF-PEOPLE=7.0
              PEOPLE-HG-SENS=200
              PEOPLE-HG-LAT=200
              LIGHTING-KW=5.0
              LIGHTING-TYPE=INCAND
              EQUIPMENT-KW=3.5
              EQUIP-SENSIBLE=0.63
              EQUIP-LATENT=0.37          ..

SOUTH-EL      =EXTERIOR-WALL
              LOCATION=FRONT
              CONSTRUCTION=W1-1  ..

              DOOR-S1      =DOOR   H=7    W=3    X=20   Y=0
                                   CONSTRUCTION=DOOR-1        ..
              WINDOW-S1-1=WINDOW   H=4    W=6    X=6    Y=3
```

```
                                GLASS-TYPE=GLASS-1            ..
            WINDOW-S1-2=WINDOW  H=4     W=2     X=18    Y=3
                                GLASS-TYPE=GLASS-1            ..
            WINDOW-S1-3=WINDOW  H=4     W=2     X=24    Y=3
                                GLASS-TYPE=GLASS-1            ..
            WINDOW-S1-4=WINDOW  H=4     W=2     X=32    Y=3
                                GLASS-TYPE=GLASS-1            ..
            WINDOW-S1-5=WINDOW  H=4     W=4     X=42    Y=3
                                GLASS-TYPE=GLASS-1            ..
            WINDOW-S2-1=WINDOW  H=4     W=6     X=6     Y=12.75
                                GLASS-TYPE=GLASS-1            ..
            WINDOW-S2-2=WINDOW  H=4     W=4     X=20    Y=12.75
                                GLASS-TYPE=GLASS-1            ..
            WINDOW-S2-3=WINDOW  H=4     W=2     X=32    Y=12.75
                                GLASS-TYPE=GLASS-1            ..
            WINDOW-S2-4=WINDOW  H=4     W=4     X=42    Y=12.75
                                GLASS-TYPE=GLASS-1            ..

WEST-EL     =EXTERIOR-WALL
            LOCATION=LEFT
            CONSTRUCTION=W1-1   ..

            DOOR-W1     =DOOR   H=7     W=3     X=34    Y=0
                                CONSTRUCTION=DOOR-1           ..
            WINDOW-W1-1=WINDOW  H=4     W=10    X=4     Y=3
                                GLASS-TYPE=GLASS-1            ..
            WINDOW-W1-2=WINDOW  H=4     W=6     X=18    Y=3
                                GLASS-TYPE=GLASS-1            ..
            WINDOW-W2-1=WINDOW  H=4     W=6     X=4     Y=12.75
                                GLASS-TYPE=GLASS-1            ..
            WINDOW-W2-2=WINDOW  H=4     W=2     X=18    Y=12.75
                                GLASS-TYPE=GLASS-1            ..
            WINDOW-W2-3=WINDOW  H=4     W=2     X=32    Y=12.75
                                GLASS-TYPE=GLASS-1            ..
            WINDOW-W2-4=WINDOW  H=4     W=6     X=38    Y=12.75
                                GLASS-TYPE=GLASS-1            ..

NORTH-EL    =EXTERIOR-WALL
            LOCATION=BACK
            CONSTRUCTION=W1-1   ..

            WINDOW-N1-1=WINDOW  H=4     W=8     X=6     Y=3
                                GLASS-TYPE=GLASS-1            ..
            WINDOW-N1-2=WINDOW  H=4     W=8     X=38    Y=3
                                GLASS-TYPE=GLASS-1            ..
            WINDOW-N2-1=WINDOW  H=4     W=4     X=6     Y=12.75
                                GLASS-TYPE=GLASS-1            ..
            WINDOW-N2-2=WINDOW  H=4     W=2     X=18    Y=12.75
                                GLASS-TYPE=GLASS-1            ..
            WINDOW-N2-3=WINDOW  H=4     W=4     X=28    Y=12.75
                                GLASS-TYPE=GLASS-1            ..
            WINDOW-N2-4=WINDOW  H=4     W=6     X=40    Y=12.75
                                GLASS-TYPE=GLASS-1            ..
```

```
EAST-EL         =EXTERIOR-WALL
                LOCATION=RIGHT
                CONSTRUCTION=W1-1     ..

                WINDOW-E1-1=WINDOW  H=4    W=4    X=4     Y=3
                                    GLASS-TYPE=GLASS-1          ..
                WINDOW-E1-2=WINDOW  H=4    W=8    X=20    Y=3
                                    GLASS-TYPE=GLASS-1          ..
                WINDOW-E1-3=WINDOW  H=4    W=4    X=40    Y=3
                                    GLASS-TYPE=GLASS-1          ..
                WINDOW-E2-1=WINDOW  H=4    W=4    X=4     Y=12.75
                                    GLASS-TYPE=GLASS-1          ..
                WINDOW-E2-2=WINDOW  H=4    W=8    X=20    Y=12.75
                                    GLASS-TYPE=GLASS-1          ..
                WINDOW-E2-3=WINDOW  H=4    W=4    X=40    Y=12.75
                                    GLASS-TYPE=GLASS-1          ..

ROOF1           =ROOF
                LOCATION=TOP
                CONSTRUCTION=R2-8          ..

END ..
COMPUTE LOADS ..

INPUT SYSTEMS
                INPUT-UNITS=ENGLISH
                OUTPUT-UNITS=ENGLISH ..

TITLE           LINE-1    * ROOFTOP AIR-CONDITIONER *
                LINE-2    * PSZ SYSTEM *
                LINE-3    * VW11R28D *
                LINE-4    * VILLA, WALL 1-1, ROOF 2-8, DHAHRAN* ..

HEAT-V          =SCHEDULE        THRU DEC 31 (ALL) (1,24) (75)  ..

COOL-V          =SCHEDULE        THRU DEC 31 (ALL) (1,24) (78)  ..

ZO-CONT-V       =ZONE-CONTROL    DESIGN-HEAT-T=75
                                 DESIGN-COOL-T=78
                                 HEAT-TEMP-SCH=HEAT-V
                                 COOL-TEMP-SCH=COOL-V
                                 THERMOSTAT-TYPE=PROPORTIONAL
                                 THROTTLING-RANGE=2.0  ..

ZO-AIR-V        =ZONE-AIR        EXHAUST-CFM=0  ..

TWO-FLOORS-V    =ZONE            ZONE-CONTROL=ZO-CONT-V
                                 ZONE-TYPE=CONDITIONED
                                 ZONE-AIR=ZO-AIR-V ..

S-CONT-V     =SYSTEM-CONTROL     MAX-SUPPLY-T=105.
                                 MIN-SUPPLY-T=52.  ..
```

```
S-AIR-V     =SYSTEM-AIR          MIN-OUTSIDE-AIR=0.20
                                 DUCT-AIR-LOSS=0
                                 DUCT-DELTA-T=0  ..

S-FAN-V     =SYSTEM-FANS         SUPPLY-KW=0.
                                 FAN-CONTROL=CONSTANT-VOLUME
                                 MOTOR-PLACEMENT=IN-AIRFLOW
                                 FAN-PLACEMENT=DRAW-THROUGH  ..

S-EQUIP-V =SYSTEM-EQUIPMENT      COOLING-EIR=0.365          ..

SYSTEM-V  =SYSTEM                SYSTEM-TYPE=PSZ
                                 SYSTEM-CONTROL=S-CONT-V
                                 SYSTEM-AIR=S-AIR-V
                                 SYSTEM-FANS=S-FAN-V
                                 SYSTEM-EQUIPMENT=S-EQUIP-V
                                 HEAT-SOURCE=ELECTRIC
                                 RETURN-AIR-PATH=DIRECT
                                 ZONE-NAMES=(TWO-FLOORS-V)  ..

SYSTEMS-REPORT     VERIFICATION=(SV-A)
                   SUMMARY=(SS-A,SS-C,SS-G,SS-H) ..
                   $EPORT-FREQUENCY=(DAILY) ..

END ..
COMPUTE SYSTEMS  ..
```

Appendix E
Simulation Outputs

REPORT- LV-A GENERAL PROJECT AND BUILDING INPUT WEATHER FILE- TRY DHAHRAN

PERIOD OF STUDY

STARTING DATE	ENDING DATE	NUMBER OF DAYS
1 JAN 1989	31 DEC 1989	365

SITE CHARACTERISTIC DATA

	STATION NAME	LATITUDE (DEG)	LONGITUDE (DEG)	ALTITUDE (FT)	TIME ZONE	BUILDING AZIMUTH (DEG)
TRY	DHAHRAN	26.3	-50.1	80.	-3	0.0

VW22R53D VILLA, WALL 2-2, ROOF 5-3, DHAHRAN DOE-2.1C 10/24/90 10:30:30.LDL RUN 1

REPORT- LV-D DETAILS OF EXTERIOR SURFACES IN THE PROJECT WEATHER FILE- TRY DHAHRAN

NUMBER OF EXTERIOR SURFACES 5 RECTANGULAR 5 OTHER 0

SURFACE	SPACE	- - - - G L A S S - - - - U-VALUE (BTU/HR - SQFT)	AREA (SQFT)	- - - - W A L L - - - - U-VALUE (BTU/HR - SQFT)	AREA (SQFT)	- W A L L + G L A S S - U-VALUE (BTU/HR - SQFT)	AREA (SQFT)	AZIMUTH
NORTH-EL	TWO-FLOORS-V	1.02	128.00	0.16	886.00	0.27	1014.00	NORTH
EAST-EL	TWO-FLOORS-V	1.02	128.00	0.16	808.00	0.28	936.00	EAST
SOUTH-EL	TWO-FLOORS-V	1.02	128.00	0.16	886.00	0.27	1014.00	SOUTH
WEST-EL	TWO-FLOORS-V	1.02	128.00	0.16	808.00	0.28	936.00	WEST
ROOF1	TWO-FLOORS-V	0.00	0.00	0.09	2496.00	0.09	2496.00	ROOF

VW22953D   VILLA, WALL 2-2, ROOF 5-3, DHAHRAN   DOE-2.1C 10/24/90   10:30:30.LDL RUN 1

REPORT- LV-D DETAILS OF EXTERIOR SURFACES IN THE PROJECT   WEATHER FILE- TRY DHAHRAN (CONTINUED)

	AVERAGE U-VALUE/GLASS (BTU/HR - SQFT)	AVERAGE U-VALUE/WALLS (BTU/HR - SQFT)	AVERAGE U-VALUE WALLS+GLASS (BTU/HR - SQFT)	GLASS AREA (SQFT)	OPAQUE AREA (SQFT)	GLASS+OPAQUE AREA (SQFT)
NORTH	1.02	0.16	0.27	128.00	886.00	1014.00
EAST	1.02	0.16	0.28	128.00	808.00	936.00
SOUTH	1.02	0.16	0.27	128.00	886.00	1014.00
WEST	1.02	0.16	0.28	128.00	808.00	936.00
ROOF	0.00	0.09	0.09	0.00	2496.00	2496.00
ALL WALLS	1.02	0.16	0.28	512.00	3388.00	3900.00
WALLS+ROOFS	1.02	0.13	0.20	512.00	5884.00	6396.00
BUILDING	1.02	0.13	0.20	512.00	5884.00	6396.00

VW22R51D VILLA, WALL 2-2, ROOF 8-3, DHAHRAN DOE-2.1C 10/24/90 10130130.LDL RUN 1

REPORT- LS-A SPACE PEAK LOADS SUMMARY WEATHER FILE- TRY DHAHRAN

SPACE NAME	MULTIPLIER SPACE	MULTIPLIER FLOOR	COOLING LOAD (KBTU/HR)	TIME OF PEAK	DRY-BULB	WET-BULB	HEATING LOAD (KBTU/HR)	TIME OF PEAK	DRY-BULB	WET-BULB
TWO-FLOORS-V	1.	1.	97.234	JUL 21 1 PM	109.F	73.F	-24.618	FEB 2 6 AM	48.F	46.F
SUM			97.234				-24.618			
BUILDING PEAK			97.234	JUL 21 1 PM	109.F	73.F	-24.618	FEB 2 6 AM	48.F	46.F

REPORT- LS-C BUILDING PEAK LOAD COMPONENTS   WEATHER FILE- TRY   DHAHRAN

*** BUILDING ***

FLOOR AREA	2496	SQFT	232	SQMT
VOLUME	48672	CUFT	1378	CUMT

	COOLING LOAD		HEATING LOAD	
TIME	JUL 21 1PM		FEB 2 6AM	
DRY-BULB TEMP	109F	43C	48F	9C
WET-BULB TEMP	73F	23C	46F	8C

	SENSIBLE (KBTU/H)	SENSIBLE (KW)	LATENT (KBTU/H)	LATENT (KW)	SENSIBLE (KBTU/H)	SENSIBLE (KW)
WALLS	14.570	4.267	0.000	0.000	-7.507	-2.199
ROOFS	5.432	1.591	0.000	0.000	-2.442	-0.716
GLASS CONDUCTION	20.875	6.114	0.000	0.000	-10.183	-2.982
GLASS SOLAR	11.091	3.248	0.000	0.000	2.504	0.733
DOOR	0.833	0.244	0.000	0.000	-0.360	-0.105
INTERNAL SURFACES	0.000	0.000	0.000	0.000	0.000	0.000
UNDERGROUND SURFACES	0.000	0.000	0.000	0.000	0.000	0.000
OCCUPANTS TO SPACE	0.787	0.230	0.700	0.205	1.259	0.369
LIGHT TO SPACE	6.677	1.956	0.000	0.000	3.176	0.930
EQUIPMENT TO SPACE	4.924	1.442	3.094	0.906	0.751	0.220
PROCESS TO SPACE	0.000	0.000	0.000	0.000	0.000	0.000
INFILTRATION	32.045	9.385	0.000	0.000	-11.817	-3.461
TOTAL	97.234	28.477	3.794	1.111	-24.618	-7.210

TOTAL LOAD	101.028 KBTU/H	29.588 KW	-24.618 KBTU/H	-7.210 KW
TOTAL LOAD / AREA	40.48BTU/H.SQFT	127.599 W /SQMT	9.863BTU/H.SQFT	31.093 W /SQMT

NOTE 1)THE ABOVE LOADS EXCLUDE OUTSIDE VENTILATION AIR LOADS
---- 2)TIMES GIVEN IN STANDARD TIME FOR THE LOCATION IN CONSIDERATION

VW22953D VILLA, WALL 2-2, ROOF 5-3, DHAHRAN DOE-2.1C 10/24/90 10130130.LDL RUN 1

REPORT- LS-D BUILDING MONTHLY LOADS SUMMARY WEATHER FILE- TRY DHAHRAN

	- - - - - - - - - C O O L I N G					- - - - - - - - -	- - - - - - - - - H E A T I N G					- - - - - - - - -	- - - E L E C	- - -
MONTH	COOLING ENERGY (MBTU)	TIME OF MAX DY	HR	DRY-BULB TEMP	WET-BULB TEMP	MAXIMUM COOLING LOAD (KBTU/HR)	HEATING ENERGY (MBTU)	TIME OF MAX DY	HR	DRY-BULB TEMP	WET-BULB TEMP	MAXIMUM HEATING LOAD (KBTU/HR)	ELEC-TRICAL ENERGY (KWH)	MAXIMUM ELEC LOAD (KW)
JAN	4.55635	22	18	63.F	56.F	19.726	-3.369	19	6	50.F	47.F	-22.932	2962.	8.496
FEB	7.61650	28	18	67.F	58.F	31.333	-1.603	2	6	48.F	46.F	-24.618	2690.	8.496
MAR	15.24056	24	18	74.F	62.F	42.142	-0.182	9	6	56.F	52.F	-9.197	3001.	8.496
APR	26.31978	23	15	90.F	68.F	62.596	0.000					0.000	2872.	8.496
MAY	40.06523	31	15	102.F	72.F	85.910	0.000					0.000	2962.	8.496
JUN	49.09109	30	15	105.F	72.F	96.828	0.000					0.000	2910.	8.496
JUL	53.49176	21	13	109.F	73.F	97.234	0.000					0.000	2962.	8.496
AUG	49.38542	3	15	105.F	72.F	92.831	0.000					0.000	2981.	8.496
SEP	41.11455	7	15	102.F	73.F	88.426	0.000					0.000	2891.	8.496
OCT	31.59138	6	16	92.F	71.F	70.711	0.000					0.000	2962.	8.496
NOV	18.01495	2	15	84.F	65.F	51.222	-0.036	30	6	59.F	55.F	-9.266	2891.	8.496
DEC	7.53968	6	18	68.F	52.F	30.480	-1.864	31	5	50.F	48.F	-21.947	2981.	8.496
TOTAL	343.027						-7.053						35066.	
MAX						97.234						-24.618		8.496

VW22R53D VILLA, WALL 2-2, ROOF 5-3, DHAHRAN DOE-2.1C 10/24/90 10130130.LDL RUN 1

REPORT- LS-F BUILDING MONTHLY LOAD COMPONENTS IN MBTU WEATHER FILE- TRY DHAHRAN

(UNITS=MBTU)		WALLS	ROOFS	INT SUR	UND SUR	INFIL	GL CON	GL SOL	OCCUP	LIGHTS	EQUIP	SOURCE	TOTA
JAN	HEATNG	-1.947	-0.674	0.000	0.000	-2.645	-2.418	1.310	0.367	1.879	0.759	0.000	-3.368
	SEN CL	-1.884	-0.957	0.000	0.000	-1.702	-1.850	4.723	0.449	3.643	8.134	0.000	4.856
	LAT CL					0.084			0.486		1.351	0.000	1.891
FEB	HEATNG	-0.991	-0.296	0.000	0.000	-1.850	-1.433	0.886	0.283	1.182	0.436	0.000	-1.603
	SEN CL	-1.225	-0.640	0.000	0.000	-1.234	-1.398	5.876	0.481	3.858	8.198	0.000	7.616
	LAT CL					0.217			0.481		1.367	0.000	2.068
MAR	HEATNG	-0.152	-0.022	0.000	0.000	-0.314	-0.293	0.176	0.070	0.264	0.089	0.000	-0.182
	SEN CL	0.370	0.161	0.000	0.000	-0.316	-0.502	6.639	0.739	5.304	8.846	0.000	15.240
	LAT CL					0.987			0.738		1.698	0.000	3.393
APR	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	3.893	1.653	0.000	0.000	2.640	2.362	6.811	0.789	5.363	2.810	0.000	26.320
	LAT CL					1.997			0.789		1.648	0.000	4.433
MAY	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	7.933	3.083	0.000	0.000	7.293	6.314	6.818	0.817	5.822	2.893	0.000	40.066
	LAT CL					3.416			0.817		1.699	0.000	5.930
JUN	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	10.215	3.904	0.000	0.000	10.850	8.895	6.201	0.782	5.398	2.848	0.000	49.093
	LAT CL					2.770			0.781		1.675	0.000	5.226
JUL	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	11.352	4.292	0.000	0.000	11.722	9.821	6.061	0.816	5.533	2.897	0.000	52.494
	LAT CL					5.571			0.817		1.699	0.000	8.086
AUG	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	10.755	4.088	0.000	0.000	10.429	9.010	5.841	0.813	5.540	2.912	0.000	49.387
	LAT CL					6.198			0.813		1.712	0.000	10.723
SEP	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	8.705	3.301	0.000	0.000	7.331	6.660	6.112	0.788	5.391	2.833	0.000	41.116
	LAT CL					9.074			0.788		1.661	0.000	11.521
OCT	HEATNG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	SEN CL	5.760	2.112	0.000	0.000	4.000	3.769	6.720	0.817	5.522	2.893	0.000	31.593
	LAT CL					6.288			0.817		1.699	0.000	8.803
NOV	HEATNG	-0.021	-0.001	0.000	0.000	-0.079	-0.070	0.042	0.020	0.059	0.015	0.000	-0.036
	SEN CL	1.578	0.447	0.000	0.000	0.423	0.302	6.379	0.766	5.310	2.810	0.000	18.015
	LAT CL					2.602			0.765		1.641	0.000	5.028
DEC	HEATNG	-1.106	-0.358	0.000	0.000	-1.723	-1.566	0.806	0.276	1.308	0.303	0.000	-1.864
	SEN CL	-1.317	-0.725	0.000	0.000	-1.320	-1.498	5.189	0.836	4.287	2.417	0.000	7.840
	LAT CL					0.475			0.830		1.600	0.000	2.814
TOT	HEATNG	-4.216	-1.351	0.000	0.000	-6.312	-5.780	3.160	0.956	4.689	1.802	0.000	-7.053
	SEN CL	56.102	20.704	0.000	0.000	50.086	41.858	72.416	8.588	60.896	32.458	0.000	342.806
	LAT CL					41.625			8.596		19.363	0.000	69.884

ROOFTOP AIR-CONDITIONER PSZ SYSTEM DOE-2.1C 10/24/90 10:30:30.SDL RUN 1
VW22R53D VILLA, WALL 2-2, ROOF 5-3, DHAHRAN DHAHRAN CLIMATE (70/10B)
REPORT- SV-A SYSTEM DESIGN PARAMETERS SYSTEM-V-7.1-3 WEATHER FILE- TRY DHAHRAN

SYSTEM NAME	ALTITUDE MULTIPLIER
SYSTEM-V-7.1-3	1.000

SUPPLY FAN (CFM)	ELEC (KW)	DELTA-T (F)	RETURN FAN (CFM)	ELEC (KW)	DELTA-T (F)	OUTSIDE AIR RATIO	COOLING CAPACITY (KBTU/HR)	SENSIBLE (SHR)	HEATING CAPACITY (KBTU/HR)	COOLING EIR (BTU/BTU)	HEATING EIR (BTU/BTU)
2400.	1.408	1.6	2400.	0.000	0.0	0.333	101.028	0.962	-34.129	0.37	0.37

ZONE NAME	SUPPLY FLOW	EXHAUST FLOW	FAN (KW)	MINIMUM FLOW RATIO	OUTSIDE AIR FLOW	COOLING CAPACITY (KBTU/HR)	SENSIBLE (SHR)	EXTRACTION RATE (KBTU/HR)	HEATING CAPACITY (KBTU/HR)	ADDITION RATE (KBTU/HR)	MULTIPLIER
TWO-FLOORS-V	2400.	0.	0.000	1.000	800.	0.00	0.00	37.51	0.00	-15.86	1.0

ROOFTOP AIR-CONDITIONER PSZ SYSTEM DOE-2.1C 10/24/90 10130130.SDL RUN 1
VW22R53D VILLA, WALL 2-2, ROOF 5-3, DHAHRAN DHAHRAN CLIMATE (70/105)
REPORT- SS-A SYSTEM MONTHLY LOADS SUMMARY FOR SYSTEM-V-7.1-3 WEATHER FILE- TRY DHAHRAN

	- - - C O O L I N G - - -						- - - H E A T I N G - - -						- - - E L E C - - -	
MONTH	COOLING ENERGY (MBTU)	TIME OF MAX DY	HR	DRY-BULB TEMP	WET-BULB TEMP	MAXIMUM COOLING LOAD (KBTU/HR)	HEATING ENERGY (MBTU)	TIME OF MAX DY	HR	DRY-BULB TEMP	WET-BULB TEMP	MAXIMUM HEATING LOAD (KBTU/HR)	ELEC-TRICAL ENERGY (KWH)	MAXIMUM ELEC LOAD (KW)
JAN	0.00000					0.000	-12.961	30	5	50.F	47.F	-34.915	7680.	15.872
FEB	0.01806	28	14	74.F	57.F	4.857	-6.809	3	6	49.F	47.F	-34.722	5723.	15.836
MAR	3.14272	24	14	80.F	61.F	28.688	-2.087	9	6	56.F	52.F	-23.968	5043.	12.281
APR	17.56438	22	18	84.F	69.F	61.475	-0.087	2	5	62.F	58.F	-6.091	5740.	16.187
MAY	39.13019	27	19	90.F	73.F	79.305	0.000					0.000	8240.	18.414
JUN	46.54800	21	20	90.F	74.F	83.807	0.000					0.000	9184.	19.291
JUL	55.22974	22	19	96.F	79.F	104.317	0.000					0.000	10252.	20.986
AUG	58.19659	8	20	93.F	79.F	102.783	0.000					0.000	10452.	20.609
SEP	54.34506	9	19	89.F	80.F	104.646	0.000					0.000	9651.	20.416
OCT	36.64920	13	23	77.F	73.F	95.304	0.000					0.000	7737.	19.255
NOV	8.36493	4	19	77.F	70.F	70.690	-0.940	26	5	58.F	53.F	-18.444	5089.	16.532
DEC	0.14145	5	13	75.F	64.F	11.281	-8.204	31	4	50.F	46.F	-34.639	6820.	15.828
TOTAL	319.175						-31.040						91434.	
MAX						104.646						-34.915		20.986

ROOFTOP AIR-CONDITIONER PSZ SYSTEM DOE-2.1C 10/24/90 10130130.SDL RUN 1
VW22R53D VILLA, WALL 2-2, ROOF 5-3, DHAHRAN DHAHRAN CLIMATE (70/105)
REPORT- SS-C SYSTEM MONTHLY LOAD HOURS FOR SYSTEM-V-7.1-3 WEATHER FILE- TRY DHAHRAN

	- - - - - - N U M B E R	O F	H O U R S - - - - - -								--COINCIDENT LOADS--	
MONTH	HOURS COOLING LOAD	HOURS HEATING LOAD	HOURS COINCIDENT COOL-HEAT LOAD	HOURS FLOATING	HOURS HEATING AVAIL.	HOURS COOLING AVAIL.	HOURS FANS ON	HOURS FANS CYCLE ON	HOURS NIGHT VENTING	HOURS FLOATING WHEN FANS ON	HEATING LOAD AT COOLING PEAK (KBTU/HR)	ELECTRIC LOAD AT COOLING PEAK (KW)
JAN	0	740	0	4	744	744	744	0	0	4	-25.404	12.497
FEB	10	428	0	234	672	672	672	0	0	234	0.000	4.998
MAR	248	204	0	292	744	744	744	0	0	292	0.000	8.931
APR	568	12	0	140	720	720	720	0	0	140	0.000	16.187
MAY	743	0	0	1	744	744	744	0	0	1	0.000	18.414
JUN	720	0	0	0	720	720	720	0	0	0	0.000	18.825
JUL	744	0	0	0	744	744	744	0	0	0	0.000	20.986
AUG	744	0	0	0	744	744	744	0	0	0	0.000	20.609
SEP	720	0	0	0	720	720	720	0	0	0	0.000	20.369
OCT	662	0	0	82	744	744	744	0	0	82	0.000	18.639
NOV	349	123	0	248	720	720	720	0	0	248	0.000	16.532
DEC	29	519	0	196	744	744	744	0	0	196	0.000	5.659
ANNUAL	5537	2026	0	1197	8760	8760	8760	0	0	1197		

ROOFTOP AIR-CONDITIONER　　PSZ SYSTEM　　DOE-2.1C 10/24/90　　10:30:30.SDL RUN 1
VW22R530　　VILLA, WALL 2-2, ROOF 5-3, DHAHRAN　　DHAHRAN CLIMATE (70/105)
REPORT- SS-H SYSTEM MONTHLY LOADS SUMMARY FOR　　SYSTEM-V-7.1-3　　WEATHER FILE- TRY　　DHAHRAN

MONTH	----FAN ELEC---- FAN ELECTRIC ENERGY (KWH)	MAXIMUM FAN ELECTRIC LOAD (KW)	--FUEL HEAT---- GAS OIL HEATING ENERGY (MBTU)	MAXIMUM GAS OIL HEATING LOAD (KBTU/HR)	--ELEC HEAT--- ELECTRIC HEATING ENERGY (KWH)	MAXIMUM ELECTRIC HEATING LOAD (KW)	---ELEC COOL--- ELECTRIC COOLING ENERGY (KWH)	MAXIMUM ELECTRIC COOLING LOAD (KW)
JAN	1048.	1.408	0.00000	0.000	3796.	10.226	74.	0.100
FEB	946.	1.408	0.00000	0.000	2018.	10.169	69.	0.591
MAR	1048.	1.408	0.00000	0.000	594.	7.020	401.	3.075
APR	1014.	1.408	0.00000	0.000	8.	1.784	1847.	6.307
MAY	1048.	1.408	0.00000	0.000	0.	0.000	4231.	8.850
JUN	1014.	1.408	0.00000	0.000	0.	0.000	5260.	9.777
JUL	1048.	1.408	0.00000	0.000	0.	0.000	6242.	11.294
AUG	1048.	1.408	0.00000	0.000	0.	0.000	6423.	10.806
SEP	1014.	1.408	0.00000	0.000	0.	0.000	5747.	10.592
OCT	1048.	1.408	0.00000	0.000	0.	0.000	3728.	9.388
NOV	1014.	1.408	0.00000	0.000	275.	5.402	909.	6.627
DEC	1048.	1.408	0.00000	0.000	2403.	10.145	89.	1.251
TOTAL	12325.		0.000		9091.		35010.	
MAX		1.408		0.000		10.226		11.294

ROOFTOP AIR-CONDITIONER   PSZ SYSTEM   DOE-2.1C 10/24/90   10130130.SDL RUN 1
VW22853D   VILLA, WALL 2-2, ROOF 5-3, DHAHRAN   DHAHRAN CLIMATE (70/105)
REPORT- SS-G ZONE LOADS SUMMARY IN   SYSTEM-V-7.1-3 FOR TWO-FLOORS-V   WEATHER FILE- TRY DHAHRAN

	- - - C O O L I N G - - -					- - - H E A T I N G - - -					- - E L E C - -	
MONTH	COOLING ENERGY (MBTU)	TIME OF MAX DY HR	DRY-BULB TEMP	WET-BULB TEMP	MAXIMUM COOLING LOAD (KBTU/HR)	HEATING ENERGY (MBTU)	TIME OF MAX DY HR	DRY-BULB TEMP	WET-BULB TEMP	MAXIMUM HEATING LOAD (KBTU/HR)	ELEC-TRICAL ENERGY (KWH)	MAXIMUM ELEC LOAD (KW)
JAN	0.00000				0.000	0.000				0.000	2962.	8.496
FEB	0.00000				0.000	0.000				0.000	2690.	8.496
MAR	0.00000				0.000	0.000				0.000	3001.	8.496
APR	0.00000				0.000	0.000				0.000	2871.	8.496
MAY	0.00000				0.000	0.000				0.000	2962.	8.496
JUN	0.00000				0.000	0.000				0.000	2910.	8.496
JUL	0.00000				0.000	0.000				0.000	2962.	8.496
AUG	0.00000				0.000	0.000				0.000	2981.	8.496
SEP	0.00000				0.000	0.000				0.000	2891.	8.496
OCT	0.00000				0.000	0.000				0.000	2962.	8.496
NOV	0.00000				0.000	0.000				0.000	2891.	8.496
DEC	0.00000				0.000	0.000				0.000	2981.	8.496
TOTAL	0.000					0.000					35049.	
MAX					0.000					0.000		8.496

REFERENCES

1. Meyer, William T. *Energy Economics and Building Design.* New York: McGraw-Hill Book Company, 1983.

2. Balghanim, A.M. Bin Sulaiman. "The Need for Using Thermal Insulations in the Kingdom of Saudi Arabia." *Al-Mohandis.* Vol. 2, No. 1, Safar 1409 H, pp. 18-29.

3. Grondzik, Walter T. "Architectural Applications of Thermal Insulation." *Al-Mohandis.* Vol. 2, No. 1, Safar 1409 H, pp. 2-11.

4. Joubert, P.H. and E.H. Mathews. "QuickTEMP- A Thermal analysis program for Designers of Naturally Ventilated Buildings." *Building and Environment.* Vol. 24, No. 2, 1989, pp. 155-162.

5. Clarke, J.A. and A.D. Irving. "Building Energy Simulation: An Introduction." *Energy and Buildings.* Vol. 10, No. 3, January 18, 1988, pp. 157-159.

6. Simon, H.A. *A Student's Introduction to Energy Design.* New York: Pergamon Press, 1975.

7. Newton, David, Roger James, and David Bartholomew. "Building Energy Simulation- A User's Perspective." *Energy and Buildings.* Vol. 10, No. 3, January 18, 1988, pp. 241-247.

8. Stoecker, W.F. *Design of Thermal Systems.* New York: McGraw-Hill, 1971, pp. 78-80.

9. Grondzik, W., A. Al-Hammad, and N. Harm. *Thermal and Economic Performance of Insulation for Saudi Buildings: KACST Progress Report No. 3.* Dhahran: K.F.U.P.M, 1987.

10. Dell'Isola, Alphonse J. and Stephen J. Kirk. *Life Cycle Costing for Design Proffesionals.* New York: McGraw-Hill Book Company, 1981.

11. Riggs, James L. and Thomas M. West. *Essentials of Engineering Economics.* New York: McGraw-Hill Book Company, 1986.

12. *Energy Conservation Program - Appendix No. 2: Energy Conservation Measures in Residential Sector Buildings.* Kuwait: Ministry of Electricity and Water, 1983.

13. ENSAR Group, Inc. *Energy Efficiency Standards for Buildings in the Kingdom of Saudi Arabia: Review Draft.* Dammam: Arabian Fiberglass Insulation Company, Ltd., 1989.

14. Zaitoun, Ahmad M. *Practical Use of Insulation Materials in Eastern Province of Saudi Arabia: Senior Thesis II.* Dhahran: King Fahd University of Petroleum and Minerals, 1988.

15. Al-Zahrani, Ali A. *Cost Analysis Updated for Insulation Materials and its Installation in Saudi Arabia: Senior Thesis II.* Dhahran: King Fahd University of Petroleum and Minerals, 1990.

16. Arabian Gulf Countries Council. *Regulation for Thermal Insulation for Buildings.* Doha, Qatar, October, 1984.

17. Grondzik, Walter, Abdulmuhsin Al-Hammad and Brooks Washburn. *Thermal and Economic Performance of Insulation for Saudi Buildings: KACST Progress Report No. Five.* Dhahran: King Fahd University of Petroleum and Minerals, 1990.

18. Grondzik, W., A. Al-Hammad, and N. Harm. *Thermal and Economic Performance of Insulation for Saudi Buildings: KACST Progress Report No. 4.* Dhahran: K.F.U.P.M, 1988.

19. Fereig, S.M. and M.A. Younis. "Effects of Energy Conservation Measures on the Life Cycle Cost of Kuwaiti Residential Buildings." *Energy and Buildings.* Vol. 8, 1985, pp. 71-78.

20. Department of Energy. *DOE-2 Manual.* Washington, D.C.: Department of Energy.

21. Al-Abdullah, Anwar. *(Verbal Interview at SCECO Department).* Khobar: 1990.

22. *SCECO Customer's Guide.* Dammam: SCECO, 1410 H.

23. Abdul-Hadi, A. *Evaluation of Economical Engineering Models for Buildings Energy Studies: Senior Thesis II.* Dhahran: King Fahd University of Petroleum and Minerals, 1988.

24. Yousef, Khaled A. *Evaluation of Insulation and HVAC Systems for Residential Buildings in Hot Arid Regions Using the DOE-2.1C Computer Program: Senior Thesis II.* Dhahran: King Fahd University of Petroleum and Minerals, 1990.

25. Al-Anani, Ali and Adham Saba-Alaish. "Thermal Insulation of Buildings: Energy Conservation and Comfort Assurance". *The Jordanian Engineer.* No. 31,February, 1986, pp. 30-39.

26. Albrecht, R. J. "Study Periods and Energy Price Escalation Rates - Important Factors in the Economic Evaluation of Insulation Systems." *Thermal Insulation, Materials, and Systems for Energy Conservation in the '80s, ASTM STP 789, F. A. Govan, D. M. Greason, and J. D. McAllister, Eds.* American Society for Testing and Materials, 1983, pp. 161-175.

VITA

HADEEL NOMAN SAIED AHMED finished his high school in 1983 from Al-Faisal High School in Jeddah, Saudi Arabia. He joined King Fahd University of Petroleum and Minerals (KFUPM) at Dhahran, Saudi Arabia, in the same year. He graduated from KFUPM with a BACHELOR DEGREE with HONOR in ARCHITECTURAL ENGINEERING in June 1988. In the same year, he re-joined KFUPM as a graduate student in Construction Engineering and Management Program. He graduated from KFUPM with a MASTER DEGREE in CONSTRUCTION ENGINEERING AND MANAGEMENT in August 1991.